#1

Rocale Timmons

From:	Kathleen Butler <kathleen.butler.kb@gmail.com>
Sent:	Friday, February 14, 2014 7:17 AM
To:	Rocale Timmons
Subject:	Tiffany Park Reserve Meeting Person of Interest list

My name is Kathleen Butler, I would like to be put on the person of Interest List for the Tiffany Park Reserve. I attended the Meeting last week and was pleased to met you and others from the City planning.

I live on 18th street and I'm very concerned about the issues raised at this meeting.
I feel that the city needs to consider a new **Traffic Analysis**, for 18th St. and surrounding area, including Ponderosa at top of 116th, that is Fair and unbiased, that the Developer is not part of.
Also the impact of the possibility of the 124th entrance, that will bring more traffic short cutting thur our neighborhood like it does on Pierce and Index coming from Fairwood. Maple Valley,Kent, and Renton East use our neighborhood as a short cut to avoid 167 and Maple Valley Highway.

I would like to let you know that we have **Handicap residents and visitors** daily that need to park on our street. We must keep the street parking on 18th.We have a sloped driveway and are unable to get out of our cars on the driveway. My **handicap** parents (who also live in Renton) park on the street in front of the house. They are unable to walk but short distances.

One other concern of mine is the Loss of our wild life. We in Tiffany Park take pride in still having some wild like. I would like to know if the city plans on a **Habitat Study** with a **Wildlife Specialist**.
This is something very important to all of us.

Also I would like to know if the Mayor is aware of our concerns or do we need to email him.

Please keep me informed Thank you,

Kathleen Butler
Kathleen.butler.rb@gmail.com

#2

Rocale Timmons

From: Mary&Jim <jmhbr@aol.com>
Sent: Saturday, February 08, 2014 10:35 AM
To: Rocale Timmons; Chip Vincent; jmhbr@aol.com
Subject: Tiffany Park Woods Development

Follow Up Flag: Follow up
Flag Status: Flagged

Feb. 8, 2014

ATTN: Rocale Timmons, Senior Planner
C.E.Vincent, Administrator/Planning Director

Subject: Tiffany Park Woods Development

In response to the meeting for the Tiffany Park woods, we wish to state that we are against the development of the area.

We are worried about the impact the traffic will have. If the developer cannot get the approval to open 124th pl. SE, it will force an unacceptable amount of traffic onto SE 118th St. and Monroe Avenue SE.

The use of retention ponds you are suggesting is disturbing, because the water from the wetlands already drains onto our property and causes the yard to become soggy during the rainy season. If there is more drainage from the proposed retention ponds, we fear that it would cause our house to settle, the foundation to crack, or the structure itself to be damaged.

Jim and Mary Haber

1716 Monroe Ave. SE.
Renton, WA 98058
425-271-0147
jmhbr@aol.com

#3

Rocale Timmons

From: Georgerock <georgerock518@comcast.net>
Sent: Saturday, February 08, 2014 5:04 PM
To: ABCD
Subject: Meeting at Tiffany Park School on February 6, 2014

Follow Up Flag: Follow up
Flag Status: Flagged

Rocale Timmons — Senior Planner
Jan Illian — Plan Reviewer
Department of Community & Economics Development, Planning Division
Renton Washington (425)-430-7219
rtimmons@rentonwa.gov jilliian@renton.wa.gov

As I stated at the meeting my concerns are:

1. After attending the meeting at Tiffany Park School on February 6, 2014 after being informed by the neighbors. I was surprised that the only people who where notified was households within 300 feet of the proposed development
Not the hole neighborhood. As stated this was published in The Renton Reporter. If you drive through the neighborhood you will notice the papers just lay their until the recycle days because there wet or don't read it. The City should send the information in the monthly Water-Sewer & garbage bill.

2. The removal of all but 102 trees out of 1,305. When I moved here and purchased a new home on Monroe ave se in 1976 that the builder's Hills or Henderson had to leave two trees per lot or replace them with new trees and if this new development is approved the builder should do the same.

3. The proposed Surface water retention/detention ponds should not even be approved. The Homes that where built behind me stating 1979 also wanted to put surface water retention/detention ponds the neighborhood had a big problem with them being here. For the reasons the safety of the children in the neighborhood and the mosquitoes hanging around the stagnant water. The builder said there not a safety hazard they will be fenced. Kids live to climb fences. After meeting with the City of Renton the builder was told no surface water retention/detention ponds. The city of Renton should do the same with this project if approved.

4. The possibility of eliminating parking on one side of the affected streets and I say why. Do we want a speed way. When I moved to the Tiffany Park neighborhood in 1976 there were only two ways in and out, one being se 16th and the other was Royal Hills drive until 1979 when the final faze was built behind Monroe ave se hooking up with this side of Fairwood. The other road opening was across the Pipeline road at the end of Kirkland ave se going into the Cascade neighborhood.

5. Which was brought up is the Tiffany Park school and how they are going to handle the overflow of children?

Spero G Rockas

Georgerock518@comcast.net
February 8, 2014

CC

Dave & Renate Beedon	Bob & Cynthia Garlough	Bill Roenicke
davebeedon@comcast.net	bob@garlough.org	risingr@integrity.com

---

This email is free from viruses and malware because avast! Antivirus protection is active.

#4

RECEIVED

FEB 19 2014

MAYOR'S OFFICE

Ponderosa Estates Housing Development
SE Edmonds Way/SE Edmonds Court/SE Edmonds Avenue
Renton, WA 98058

Jan Illian
Plan Reviewer
Department of Community and Economic Development
Development Services Division
1055 South Grady Way
Renton, WA 98057-3232

February 16, 2014

Re: The Reserve at Tiffany Park

Dear Mr. Illian:

We are writing in regards to the traffic study the City of Renton is conducting to ascertain the impact of the addition of *The Reserve at Tiffany Park* on traffic. **It is our assertion that the impact study needs to be broadened to include the Edmonds Avenue SE/SE 16th St./Edmonds Way SE intersection in order to correctly determine the true impact of the addition of 98 homes on the transportation infrastructure in the surrounding area.**

The city has already deemed the intersection of Edmonds Avenue SE/SE 16th St./Edmonds Way SE as dangerous. Members of the Ponderosa Estates community have requested on multiple occasions for the addition of a crosswalk at this intersection; however, the City of Renton will not agree to this request because a cross walk would provide a false sense of security for those crossing the intersection. If this is indeed the case, the addition of hundreds more cars going through this intersection on a daily basis will further increase the danger at this intersection.

To add to the complexity of this intersection, vehicles traveling up SE 16th St. towards the intersection are blind to pedestrian traffic because it is on a hill. Pedestrians wishing to cross SE 16th St. to the community developed and maintained Ginger Creek Park are constantly in danger as a result of cars that speed up the blind hill. An increase of traffic will further exacerbate this issue.

Vehicles exiting Edmonds Avenue SE and turning onto SE 16th St. to access Tiffany Park homes do so at a high rate of speed. This makes it nearly impossible for vehicles to safely exit Ponderosa Estates from Edmonds Way SE. More importantly, it places families in danger who are accessing the two metro bus stops on Edmonds Avenue SE. This issue will be intensified by the increase of traffic accessing Tiffany Park.

We are a very stable community, with many us having lived here for twenty plus years. We know based upon our observation of current and past traffic patterns that, although there are other entrances into Tiffany Park, our Tiffany Park neighbors take the shortest route home, down SE 16th St.
We sincerely hope that you will broaden the scope of the transportation study to include the intersection of Edmonds Avenue SE/SE 16th St./Edmonds Way SE and implement appropriate

modifications/steps to ensure that this intersection is safe for both pedestrians and vehicles with the addition of increased traffic resulting from the construction of *The Reserve at Tiffany Park*. If you have any additional questions about our concerns, please feel free to contact Sue Dahlberg at 425-228-1830, Heidi Maurer at 206-715-3593 or Cynthia Sharp at 425-226-5828.

Sincerely,

Susan R Dahlberg

The Ponderosa Estates Community

Cc: Denis Law, Mayor
Rocale Timmons, Senior Planner
Tiffany Park Neighborhood Association
Norma McQuiller, Neighborhood Coordinator
Chris Barnes, Sr., Transportation Operations Manager

Attach: Ponderosa Estates Neighborhood Signatures

Ponderosa Estates Residents

Name	Signature	Address
FRANCES ROBERTS	Frances Roberts	1700 Edmonds Way S.E.
RAY J. ROBERTS	Ray J. Roberts	1700 Edmonds Way SE
Dennis McLaughlin	D. P. McL	1633 Edmonds Way SE
JUNE Ritualo	June Rituale	1633 Edmonds Way SE
Aaron Brendehl	A	2509 Se 16th Street
Sarah Brendehl	Sarah Brendehl	2509 SE 16th Street
~~BOBBY~~ Sedgiday	[illegible]	1701 Edmonds Way SE
Diane Taylor	Diane Taylor	1709 Edmonds Way SE
Gary Taylor	~~Diane~~ Gary Taylor	1709 Edmonds Way SE
Mike Mastro	Mike Mastro	1717 Edmond Way S
Karen Collen	Karen Collen	2609 Edmonds Ct SE
Mike HARWOOD	[illegible]	2609 Edmonds Ct. SE
James Roberson	[illegible]	1724 Edmonds Way SE
Laura Kilmore	Laura	1825 Edmond Way SE
Maria Antonette Gallardo	Maria Antonette Gallardo	1832 Edmonds Way SE.
Imogene GRAVES	Imogene Graves	1808 Edmonds Way SE
Kipepeo Brown	Kipepeo Brown	1725 Edmonds Way SE
Belinda Calhoun	Belinda Cal	1708 Edmonds WySE
Art Dahlberg	AB Dahlberg	2604 SE Edmonds ct

Ponderosa Estates Residents

Name	Signature	Address
Helen Pacheco	Helen M Pacheco	1809 Edmonds Wy SE Renton, WA 98058
José B. Pacheco	[illegible]	1809 Edmonds Way SE Renton, WA 98058
Heidi S. Maurer	Heidi S Maurer	2605 Edmonds Ct SE Renton, WA 98058
Clint Maurer	[illegible]	2605 Edmonds Ct SE Renton, WA. 98058
Colleen Bowman	Colleen Bowman	2600 Edmonds Ct SE Renton WA 98058
Michael Garman	Michael Garman	1816 Edmonds Way SE Renton WA 98058
Ethel Garman	Ethel Garman	1816 Edmonds Wy SE Renton, WA 98058
BLAKE WILSON	[illegible]	1824 EDMONDS WAY. RENTON, WA 98058
Lisa Cabalquinto	L Cab	1824 Edmonds Way Renton WA 98058
Maraea Albinio	M.Albinio	1824 Edmonds Way SE Renton WA 98058
Silvestre Cesar	[illegible]	2524 Edmonsd CT SE RENTON W.A 98058
Cynthia Sharp	Cynthia Sharp	1800 Edmonds Wy SE Renton, WA 98058
Delbert Sharp	Delbert Sharp	Same as Above
Pamela Roberson	P R	1724 Edmonds Way SE Renton WA 98058
Maxwel Ligon	Max Ligon	1724 Edmonds Way SE Renton WA 98058
Vicki Hou	Vicki Hou	1717 Edmonds Way SE Renton, Wa 98058

#5

Rocale Timmons

From: Rocale Timmons
Sent: Thursday, December 12, 2013 5:55 AM
To: 'Sheryl'
Cc: Wayne Potter (wpotter@novastardev.com); Barbara Yarington (Barbara.Yarington@mainvuehomes.com) (Barbara.Yarington@mainvuehomes.com)
Subject: LUA13-001572 Comment Response Letter - Anderson

Hello Ms. Anderson,

Thank you for your email wherein you have raised concerns with respect to the Reserve at Tiffany Park Preliminary Plat (File No. LUA13-001572). This email will be added to the public record for consideration by the reviewing official and you have been added as a party of record. I will address your concerns as they have been raised.

The applicant has recently applied for Preliminary Plat and Environmental Review for the subject development. You received a notice soliciting public comment and these comments are used help the City staff complete a comprehensive review which will continue over the next couple of months. The end of the public comment period does not preclude the public from participating in the remainder of the City's review. The City encourages public involvement throughout the entire process; an example being the Public Hearing which was tentatively scheduled for January 23, 2014.

I also understand that you also have concerns related to access and you believe there is not adequate access being provided to the development. As part of our review we will be looking to ensure that the development provides adequate access.

Finally you have requested that the City delay the process in order to provide adequate time to resolve the issues you have stated in your email. While the comment period, which ended on December 10, 2013 was not the end of the process for public participation we appreciate the neighborhoods concerns with respect to adequate time to comment given the fact that there was Holiday during the comment period. As a result the City will be extending the comment period and you should receive notice within the next couple of days as to the new deadline.

Please feel free to contact me should you have any other questions or if would like to elaborate on your concerns. Again, thank you for your input.

Rocale Timmons
City of Renton - Current Planning
Senior Planner
1055 South Grady Way
Renton, WA 98057
Tel: (425) 430-7219

From: Sheryl [mailto:anderson7836@comcast.net]
Sent: Wednesday, December 11, 2013 6:59 PM
To: Rocale Timmons; jilliian@rentonwas.gov
Subject: new development in Tiffany Park

Please put on the "Person of Interest" contact list, as this new effort on the part of a developer will impact me and my neighbors significantly.

Has anyone truly done an honest evaluation about how this effort will impact the residents who live along SE 18 Street? There should be more than one primary access into such a large development, and more than one secondary access. As currently planned, this will create a very inefficient and unsafe situation for all concerned. There should be at least four access roads leading into and out of this new development.

Please consider delaying the process of this activity until it is clearly understood in the affected neighborhood, and everyone's concerns are stated and resolved.

Thank you,

Sheryl Anderson
anderson7836@comcast.net

1727 Monroe Ave. S.E.
Renton, WA 98058

#6

Larry Gorg
1800 Lake Youngs Way SE
Renton, WA 98058
January 5, 2013

City of Renton
Planning Division

JAN 05 2014

RECEIVED

Subject: Tiffany Park Reserve/LUA13-001572, ECF, PP

At the time of writing these comments, I have dealt with multiple personal and home issues and did not have time to fully engage reading this development report. However, I feel the project is too large for the stated access points my comments point in that direction. Either it needs to be trimmed down, or more access points be developed.

I am a long time resident of Tiffany Park and am retired. I have two blind dogs that I walk through the neighborhood. These comments are a result of my observations while on "dog walks."

Comments
The Transportation Report states that it is estimated 1,030 vehicle trips in the daily commuting. The report breaks down to the number both leaving and exiting for both the morning and evening in the morning.

1) Using the stated four hour commute time frame, I realize that I can expect a vehicle about every 15 to 30 seconds. This is way above we see now, even along Lake Youngs Way SE.
2) There are no estimates for non commute hours for service trucks or some one entering or exiting outside of commuting time.
3) I believe that the number of vehicle trips stated, 1,030 is low. Most of the homes in Tiffany Park neighborhood have two wage earners. Spend some time around Tiffany Park Elementary around 8:30 or 3:10. Mom drops the kids off and goes to work. Dad picks them up after returning from work.
4) While on that 1,030 count subject, another reason that I believe the count is too low is that some households in our neighborhood have more than two cars. Junior living at home while attending college? Or, Junior came back to the nest after college instead of heading out on his own? Additional car shows up when kids attain driver's age. Mom and Pop get tired of jocking a kid around and junior gets a car. Sometimes that kid has a job after school.

I see that the project desires to eliminate parking on the North side of SE 18 Street. I have to read between the lines to understand why. It goes back to the 1,030 vehicle trips.

1) The report states that there are two access points, SE 18 Street and SE 124th Street. To make SE 124th Street an access point, the project needs to cross the City of Seattle's water pipeline. To do this, an easement is needed, which as yet has not been granted. Was there an application for an easement? If not SE 18th Street becomes a busy arterial that serves one big cul-de-sac. With cars going down S 18th Street every 15 to 30 seconds, this street will become even busier than Kirkland Ave SE.
2) Regardless of the access points, our neighborhood tranquility is gone.
3) It is my belief that this project, due to its size, should have more access points, such as using the sewer easement off Olympia Ave SE.
4) Those homes on the North side of SE 18th Street often entertain and parking on the street becomes

non existent. If SE 18th Street has no parking on the North side, they will have to park someplace. Spill over might end up on Lake Youngs Way SE, but due to the increase in traffic, parking might have to be limited on Lake Youngs Way SE, too. Is it a suggestion that overflow parking end up at the park at 1902 Lake Youngs Way SE, a block away, but that parking lot at times is also full.

I have not seen any reference to the school district about this proposed development. Tiffany Park Elementary now hosts two portable classrooms and space is at a premium.

1) Does the school district know about the estimated increase in student body with this development?
2) Even if they can mitigate the estimated increase, what about the traffic this new project will generate? I already know enough to not plan any trips between 8 and 8:30 and again between 3 PM and 3:30 when school starts and concludes for the day. It very difficult to get out of my drive way during these times.
3) When the school was rebuilt in the late '90s, they had to ask for a variance because of Ginger Creek. One building intrudes within the required buffer of the buried creek. Expanding the school, which now contains two portables, may not come cheap.

Walling off the wetlands, such as Wetland A, should be avoided.

1) Who will own the wetlands after the development is complete? The city? The Tiffany Park Neighborhood association?
2) For Wetland A, there is no access other than an easement through someone's property which will impede any management issues. Abutting property owners can and will take maintenance issues into their own hands which may defeat the purpose of the wetland. Trees grow and requires maintenance. Sometimes those trees become accidents waiting to happen. Who is responsible for that maintenance? How will it be accomplished?
3) Walling off the wetlands creates mini neighborhoods. I've visited some of those wetlands and there is perfectly good dry areas around them. Why can't they be accessed by the general public?

Ingress and egress from the development shows that most users will turn right on Lake Youngs Way SE, and follow to the intersection of Royal Hills Drive SE. Turn left up to the intersection of Puget Drive and SE 116th Street.

1) The main ingress and egress from the Tiffany Park neighborhood uses SE 16th Street. This gives users a better shot of making a right turn on SE 116th Street and a left onto Puget Drive during commute times. Royal Hills Drive serves three other neighborhoods. Trying to use that intersection is an exercise in frustration during commute times.
2) Most users, even those West of SE 16th Street, use SE 16th Street over Royal Hills Drive SE
3) Some users that come down SE 18th Street, make a left onto Lake Youngs Way SE, and turn onto Glenwood Ave SE, Ferndale Ave SE, or make the jog up 18th Place and use Beacon Way SE to get onto SE 16th Street. This development will impact more than those around SE 18th Street.

Since my property abuts SE 18th Street, and it appears it will become a major arterial, what compensation can I expect to receive for living next to an arterial and having to put up with the extra noise and traffic?

#7

Rocale Timmons

From:	Roenicke <risingr@integrity.com>
Sent:	Wednesday, December 11, 2013 3:45 PM
To:	Rocale Timmons
Cc:	Jan Illian
Subject:	Tiffany Park Reserve Development LuA13-001572L

Rocale Timmmons, Jan Illian,

There are a number of concerns I have relative to development of the Tiffany Park Reserve:

1) There is only one posted sign in a public area that I am aware of, which notifies residents of the planned changes to their neighborhood. That sign is at the end of SE 18th Street where few have reason to venture. I talked to another neighbor, this afternoon who will also experience a major impact by the development. This neighbor knew nothing about what is planned to happen.

In the interest of good representative government it would seem that the public would be notified of significant planned changes to their neighborhood by our representative government, and decisions should be made in the interest of justice for all. I regards to this issue:
a) The practices of good representative government would call one or possibly two <u>evening</u> public meeting in the area to openly discuss the issue with residents long before the prime comment period is cut off. Scheduling meetings "away from the public", during the day when most people are at work . . . shame on you.
b) While the contractor is interested in maximizing his profit, good government concerned about equal justice would not allow the outside influence to add to their profits by reaching into the pockets of the local community, i.e. reducing his expenses by devaluation of their existing property.

2) The schedule of events seems to have become very tight. While activity has been going on for months, only days or very limited weeks are being allowed for those impacted in the community to learn of the activity and form their comments.

Again this gives the impression of a railroad job on the existing community. "We're just following the rules." Good management would institute rules, which promote peace. These actions give the impression of strongly favoring the outside interest.

3) Looking at the traffic study seems to gloss over what appears to me to be more than a minor consideration - the projected increase of traffic. The conclusions seem it does not appear to look any further than the immediate future.

As stated if SE 18th Street is the principle ingress / egress route for 98 homes. Generally, and minimally, one can assume two cars per home, and both cars are used daily for work transportation, and there is one utility run daily of some nature.

From an Inquiry with the Renton School System they have not determined what the impact on traffic would be, or how many students to expect at Tiffany park. They only look one and very generally two years into the future. None of the commercial companies that I have worked for over 49 in years of engineering would accept that type of response. In laying out a permanent community this vagueness can only lead to future complications.

Assume 65 of those homes will have a student at Tiffany Park and the students are driven to school (presently some neighbors only one to two blocks away see their children to and from school).

The traffic study states the project will generate 1,030 daily vehicular trips. If one assumes that number will occur over 10 hours of a day that is 103 vehicles per hour, two per minute all day long. That sounds like heavy traffic. If the 80% of that traffic (824) occurs over two hours in the morning and two hours in the evening that is 206 cars per hour, that is the passing of one traffic vehicle about every 3.5 seconds. That sound like very heavy traffic for four hours each day. I wonder how many people involved in this study would buy a home, which exists in this environment. Further, this is a significant increase for accident potential, reduced safety, at the Tiffany Park School, a traffic magnet in its own right.

One suggestion is to to ban parking on the north side of SE 18th Street. This ban would mean there is no place for a guest to park in front of my home to visit. The limited parking now is barely adequate. The city is pressing for neighborhood friendship development. If this ban is enacted, it directly opposes other program actions by the city to promote neighborhood friendship development, and significantly devalues my and other properties on SE 18th Street, in the area. SE 18 Street would become heavily traveled.

One can understand the developers desire to maximize profits. But let the local government oversee that justice occurs for all by not letting the developers profits come in part by reaching their hand into the pockets of the existing community and devaluing those properties.

The traffic needs to be more spread out, more opportunities of ingress and egress, 4 would provide a much better design. There is at least one other somewhat simple opportunity for an entrance / exit

4) I understand that there is to be some type of high concrete wall around part of the property. What a draw for the Graffiti Monsters. Has anyone watched the constant problem along 116 Avenue SE just north of 168th Street? Those board fences are a constant target.

There are other issues I would like to research and comment on, but the end of your work day is nearing, I am submitting what I now have.

Thank you for your consideration, and again this community needs more time to understand and comment on and buy into this project.

Bill Roenicke
425-271-7785

#8

December 6, 2013

12904 SE 160th Renton, WA 98058

To: City Of Renton

Re: Tiffany Park Reserve

RECEIVED
DEC 09 2013
CITY OF RENTON
PLANNING DIVISION

Land Use # LUA13-001572 ECF PP
Location: SW of Pierce Ave SE and E of end of SE 18th St.

When we purchased our home here in Fairwood (now Renton) we purchased because of this greenbelt and the wooded cozy feel.

The two pipelines gave us trails and wooded area to explore and enjoy the wildlife and birds that occupy and visit this area.

From the deer, racoons, coyotes, herons, eagles, owls, ducks, squirrels, and all other lowland animals, who occupy, pass through and rest in this area. When you say this area is currently vacant you are wrong. A beautiful forested area under your plan and new owners will become 98 lots of homes, noise, traffic, crime, and a mirror image of what Renton Highlands looks like now and is still evolving into a non-green non tree grey existance. This property was last ~~jo~~ owned by the Renton School District and was to be held as possible future school property. 92 lots is two, too much, for this beautiful piece of forest. This pipline area gives us an area of leisure and rest from our busy and hectic lives. Many families use this area for dog walking and excersise. Even the Lindberg High School track team uses this area to run along for practice.

Taking a forested area with 1,305 trees and retaining only 102 of these trees will destroy the wetlands area's. Our land and property was known as Fairlaine Woods. With this project this will no longer be true. As time evolves I see all neighborhoods lacking in green spaces. This is criminal. We need this area to retain its forest feel to provide for exploration of nature as long as it exists.

Come walk through the woods, stop and listen to what you hear and see. Don't buy into the destruction of an area that will never be returned to its natural habitat. Greed is always bad and hurts everyone. I hope you take this into consideration when making your final decision.

The Lynn Family

#19

David Beedon
1725 Pierce Avenue S.E.
Renton WA 98058
Tel. (425) 277-0945
December 10, 2013

Rocale Timmons, Senior Planner
City of Renton
1055 South Grady Way
Renton, WA 98057

CITY OF RENTON
RECEIVED
DEC 10 2013
BUILDING DIVISION

Subject: Tiffany Park Reserve / LUA13-001572 ECF, PP

Ms. Timmons:

I challenge this development and the way the City of Renton has notified residents thereof.

First, the City's method of notifying residents was inadequate. The only public notification of the proposed development was the installation of one sign at the dead end of SE 18th Street, a place with poor visibility. The manner of installation was counter-productive in that the sign was mounted on a slope above the street, making it impossible to see the development map affixed to it. The only way I could inspect the map was to stand on a six-foot stepladder. To install a sign in such a way defeats its purpose.

Second, I challenge the commenting period for responding to the City's notice sent to me in the mail. The notice was postmarked on November 26 and stated a commenting period ending on December 10. If I had received the notice on the 26th, I would have had 14 days to comment. But due to the Thanksgiving holiday (November 28), on which there was no mail delivery, I did not receive the notice until November 29th, giving me 11 days to comment. If the City is using a 14-day period for comments, the City did not meet that requirement.

As I understand it, 14 days is the typical period for commenting. Thus I ask: "Why was the commenting period shortened for this project?"

Thirdly, I challenge the notice itself because of its confusing wording in the paragraph "OPTIONAL DETERMINATION OF NON-SIGNIFICANCE, MITIGATED (DNS-M)." It is unclear how the present comment period (for the Notice of Application dated November 26, 2013) relates to the "comment periods for the project and the proposed DNS-M." Thus I must ask:

A. What is the comment period for the project and how does it differ from the present comment period?
B. When does the project comment period start and end?

I challenge the proposed developer's proposal because of the following:

1. The publicly-displayed map of the development does not specify any visual buffer around its perimeter. A visual buffer is needed to preserve the attractiveness---and thus the value---of the neighborhoods bordering the site. In addition, the present woods provide a sound buffer for the existing residents. The presence of the woods has contributed to the desirability of living in this area. Many houses in this area were purchased in part because of the presence of the woods on the site.

   I ask the City to deny the developer's proposal because of this shortcoming and require the developer to provide a visual buffer of existing trees and other vegetation along the site's perimeter. A buffer of newly-planted trees would be inadequate because decades would be required to approximate the type of buffer existing vegetation provides.

2. I have seen no explanation by the developer or the City about the fact that existing streets are going to be inundated with more vehicles. Even if the developer gets permission to use 124th Place S.E. as an access point, the existing neighborhoods will be subjected to a flood of additional street traffic on a daily basis. For example, if 100 houses are built, that could equate to as many as two hundred vehicles entering and exiting the site every work day, and most of that during morning and afternoon rush hours. I would not want that level of traffic on my street and would not wish such a condition on anyone else.

   The City can mitigate this problem by limiting the number of houses in the development to a much lower number, perhaps 50 houses.

3. The wetlands on the site as defined by the surveyors are inadequately depicted to the citizenry for two reasons:

   A. As far as I can tell, there is no marking on the site that shows how the surveyors defined the extent of wetlands. If they did mark the wetland boundaries, they did so in a way that ordinary citizens cannot recognize. Thus citizens have no way of knowing how accurate the map is.

      Thus before the City approves the developer's proposal, it should require the developer to have surveyors mark in an obvious manner the wetland boundaries *as plotted on the their topographic map and on the preliminary plat*. Then citizens can have a better understanding of the proposed development.

B. The surveyors who created the topographic map of the site made their measurements at a time when there had been very low rainfall for an extended period. Thus the full extent of the wetlands was not obvious.

   Thus before the City approves the developer's proposal, it should require the developer to have surveyors survey the wetlands after an extended period of rainfall (and mark the wetland boundaries in an obvious manner).

4. The proposed development does not indicate an intention to preserve any paths that have existed on the site for decades. The surveyors's topographic map only indicates the path that connects the end of Southeast 18th Street with the Mercer Island pipeline right-of-way. It does not indicate the system of paths elsewhere on the site. These paths have existed for decades and thus represent public rights-of-way. They were in place when I moved here in 1980. They are used as shortcuts across the site, for observing nature, and walking dogs. They are also used by people playing "airsoft" games in the woods. The preliminary plat shows that none of them is being preserved.

   Thus the City should require the developer to preserve as many of these paths as possible in the public interest. Public access to the wetlands is important.

I wish to become a party of record for this project.
Thank you.

Sincerely,

David Beedon

David Beedon

Rocale Timmons

From:	Dave Beedon <davebeedon@comcast.net>
Sent:	Tuesday, December 10, 2013 1:51 PM
To:	Rocale Timmons
Subject:	Tiffany Park Reserve / LUA13-001572 ECF, PP
Follow Up Flag:	Follow up
Flag Status:	Flagged

David Beedon
December 10, 2013

Rocale Timmons, Senior Planner
City of Renton
1055 South Grady Way
Renton, WA 98057

Subject: Tiffany Park Reserve / LUA13-001572 ECF, PP

Ms. Timmons:

I challenge the Tiffany Park Rreserve development and the way the City of Renton has notified residents thereof.

First, the City's method of notifying residents was inadequate. The only public notification of the proposed development was the installation of one sign at the dead end of SE 18th Street, a place with poor visibility. The manner of installation was counter-productive in that the sign was mounted on a slope above the street, making it impossible to see the development map affixed to it. The only way I could inspect the map was to stand on a six-foot stepladder. To install a sign in such a way defeats its purpose.

Second, I challenge the commenting period for responding to the City's notice sent to me in the mail. The notice was postmarked on November 26 and stated a commenting period ending on December 10. If I had received the notice on the 26th, I would have had 14 days to comment. But due to the Thanksgiving holiday (November 28), on which there was no mail delivery, I did not receive the notice until November 29th, giving me 11 days to comment. If the City is using a 14-day period for comments, the City did not meet that requirement.

As I understand it, 14 days is the typical period for commenting. Thus I
ask: "Why was the commenting period shortened for this project?"

Thirdly, I challenge the notice itself because of its confusing wording in the paragraph "OPTIONAL DETERMINATION OF NON-SIGNIFICANCE, MITIGATED (DNS-M)." It is unclear how the present comment period (for the Notice of Application dated November 26, 2013) relates to the "comment periods for the project and the proposed DNS-M." Thus I must ask:
A. What is the comment period for the project and how does it differ from the present comment period?
B. When does the project comment period start and end?

I challenge the proposed developer's proposal because of the following:
1. The publicly-displayed map of the development does not specify any visual buffer around its perimeter. A visual buffer is needed to preserve the attractiveness---and thus the value---of the neighborhoods bordering the site. In addition, the

present woods provide a sound buffer for the existing residents. The presence of the woods has contributed to the desirability of living in this area. Many houses in this area were purchased in part because of the presence of the woods on the site.

I ask the City to deny the developer's proposal because of this shortcoming and require the developer to provide a visual buffer of existing trees and other vegetation along the site's perimeter. A buffer of newly-planted trees would be inadequate because decades would be required to approximate the type of buffer existing vegetation provides.
2. I have seen no explanation by the developer or the City about the fact that existing streets are going to be inundated with more vehicles.
Even if the developer gets permission to use 124th Place S.E. as an access point, the existing neighborhoods will be subjected to a flood of additional street traffic on a daily basis. For example, if 100 houses are built, that could equate to as many as two hundred vehicles entering and exiting the site every work day, and most of that during morning and afternoon rush hours. I would not that level of traffic on my street and would not wish such a condition on anyone else.

The City can mitigate this problem by limiting the number of house in the development to a much lower number, perhaps 50 houses.
3. The wetlands on the site as defined by the surveyors are inadequately depicted to the citizenry for two reasons:
A. As far as I can tell, there is no marking on the site that shows how the surveyors defined the extent of wetlands. If they did mark the wetland boundaries, they did so in a way that ordinary citizens cannot recognize. Thus citizens have no way of knowing how accurate the map is.

Thus before the City approves the developer's proposal, it should require the developer to have surveyors mark in an obvious manner the wetland boundaries as plotted on the their topographic map and on the preliminary plat. Then citizens can have a better understanding of the proposed development.
B. The surveyors who created the topographic map of the site made their measurements at a time when there had been very low rainfall for an extended period. Thus the full extent of the wetlands was not obvious.

Thus before the City approves the developer's proposal, it should require the developer to have surveyors survey the wetlands after an extended period of rainfall (and mark the wetland boundaries in an obvious manner).
4. The proposed development does not indicate an intention to preserve any paths that have existed on the site for decades. The surveyors's topographic map only indicates the path that connects the end of Southeast 18th Street with the Mercer Island pipeline right-of-way. It does not indicate the system of paths elsewhere on the site. These paths have existed for decades and thus represent public rights-of-way. They were in place when I moved here in 1980. They are used a shortcuts across the site, for observing nature, and walking dogs. They are also used by people playing "airsoft" games in the woods. The preliminary plat shows that none of them is being preserved.

Thus the City should require the developer to preserve as many of these paths as possible in the public interest. Public access to the wetlands is important.

I wish to become a party of record for this project.
Thank you.

David Beedon
1725 Pierce Avenue S.E.
Renton WA 98058
Tel. (425) 277-0945
December 10, 2013

Rocale Timmons

From: Dave Beedon <davebeedon@comcast.net>
Sent: Tuesday, December 10, 2013 5:03 PM
To: Rocale Timmons
Subject: Tiffany Park Reserve / LUA13-001572 ECF, PP

Follow Up Flag: Follow up
Flag Status: Flagged

Rocale Timmons, Senior Planner
City of Renton
1055 South Grady Way
Renton, WA 98057

Subject: Tiffany Park Reserve / LUA13-001572 ECF, PP Ms. Timmons:
(This is a follow-up message to my e-mail message and letter of the same date.)

I challenge this development for these additional reasons:

1. The developer's remarks on the Planning Department's Environmental Checklist has two omissions:

A. In the question regarding public transportation and bus service, the developer failed to identify the nearest bus stop.

B. In the listing of wet soil plants, the most imposing such plant (Devils Club) is not mentioned. There are large specimens thereof in a drainage area feeding wetland C, some as tall as ten feet. These plants are located roughly at housing tracts 50 and 52. There are also smaller ones roughly at tract 47 or 49. It baffles me why these major plants were omitted from the listing.

2. The proposed wall along the Mercer Island Pipeline right-of-way, supposedly a stone wall up to ten feet tall, is an abomination. The height and material of the wall would be ugly and sterile compared to natural vegetation or a normal wooden fence found in residential areas.
It would create a prison-like atmosphere that would reduce the value of existing property nearby, be obnoxious to persons walking on the pipeline, and send the message to existing neighbors that their existence is undesirable. Such a wall is suitable for an industrial area, not a residential neighborhood.

3. It appears that the developer intends to basically strip the developed area of trees. This would eliminate many large, healthy trees that should be preserved. This includes several tall cottonwoods and firs. Mitigating such destruction with some street-side plantings is inadequate. The developed area should retain more of the existing healthy trees.

David Beedon

#11 ✓

Renate Beedon
1725 Pierce Avenue S.E.
Renton, WA
Tel. 206-715-3785
December 9, 2013

Rocale Timmons, Senior Planner
CED – Planning Division
City of Renton
1055 South Grady Way
Renton, WA 98057

Subject: Tiffany Park Reserve / LUA13-001572 ECF, PP

Ms. Timmons:

The following are my concerns about the development as it is proposed:

1. I would like to start out by requesting that you extend the deadline for comments on this Project by three days, as we did not receive your notification until November 29th. Your notice is dated November 26, a Tuesday before the Thanksgiving holiday and it must have been apparent that the recipients would not receive the notice three days after it was dated.

2. The impact of the proposed development will have a negative impact on residents living nearby due to
   A. Increased traffic
   B. Loss of a buffer the current woods provide
   C. Increased number of students for the already filled to capacity schools
   D. Noise during construction
   E. Decreased value of existing residential property and decreased quality of life. Many residents purchased homes in this area because of the woods and the buffer (sight and sound) they provide from other neighborhoods. I request that the city of Renton deny this development or at least reduce the amount of houses to be built and require a visual buffer of vegetation around its perimeter.

3. The impact to the environment is also significant, as there are wetlands and various wildlife in these woods.
   A. In my opinion, the wetlands are larger than the developer has outlined. I challenge the classification of those wetlands. I request that an assessment by an independent agency be performed as to the amount, size and classification of those wetlands.
   B. I believe that the studies provided by the developer are outdated and incorrect as the last wetland study was done after 2 months of draught. I request a copy of all the studies be made available.
   C. I oppose the storm water detention vault.
   D. There are numerous old trees in these woods and they should be preserved. I request an independent study of the trees. I dispute the number of trees quoted in your notice.

E. There is a considerable amount of wildlife in these woods, i.e. deer, bobcats, mountain beavers, pileated woodpeckers, hawks and more. I request an explanation on what is planned for the displaced wildlife. I also request that no trees be cut during nesting season.
F. Development will cause rats in the woods to seek other places to live. They might all migrate to the neighboring properties. What is the developer and the City of Renton planning to do to mitigate this possibility?

4. I would like to know if there is a mine under this property and what impact that may have.

5. I request that the developer leave a buffer of trees along the Mercer Island Pipeline – this would provide a visual buffer for the existing houses east of that pipeline.

6. A path that goes from the Mercer Island Pipeline to the end of S.E. 18th Street has been used by residents as a shortcut for over 30 years. Will that path still be available to the current residents?

7. I challenge and oppose the proposed access extended from 124th Place S.E. , crossing the Cedar River Pipeline. This access would increase traffic in an established neighborhood and would require the cutting of several beautiful old trees. This pipeline is used for recreational purposes and has been for over 30 years. Traffic crossing that pipeline would interrupt these recreational activities. Apparently, the developer has not gotten an agreement from Seattle City Light to build a road across the pipeline. I challenge that the City gives permission for the development before this agreement has been reached.

8. I request a statement from the Renton Fire Department that this new development meets the requirements for easy access in case of emergencies.

9. I request that you change the time of the public hearing on January 23rd from 10 am to a time after 5:30 p.m. to make it easier for working people to attend.

10. I challenge the paragraph "Optional Determination of non-significance, mitigated (DNS-M) for the reason that it is not clear when the comment and the appeal periods start and end, i.e. which phase are we in now? This notice of application does not state clearly what the appeal and comment periods for the project are.

Sincerely,
Renate Beedon

#12

Anthony & Margaret Dean
16917 114th Ave. SE
Renton, WA 98055

December 5, 2013

City of Renton
Mr. Timmons, Senior Planner
Planning Division
1055 Grady Way
Renton, WA 9057

Re: Development of plat #2123059061, 2123059051 and 2123059044

Dear Senior Planner:

We are writing regarding the proposed development of the three above plats in the Tiffany Park woods. We are joining the neighbors in that area in opposing this development, even though we do not live in that immediate area. We have many reasons. We have walked the trails and woods for many years. I will list some of our concerns.

We live in the "old" part of 114th Ave SE, have lived here for well over 20 years. There used to be a few acres of woods at the south end of our road and we had walked our dogs through there many times. It was always wet, as a natural stream ran between our road and 116th Ave SE. Our neighbors, on two occasions, fought builders who wanted to build there and when they discovered the running water they "went away." However, as you probably know, 10 years ago we lost our fight, even though the man who was testing the soil told me that it was the worst building site he had ever tested. It was in the days of King County, and we do not believe the King Co. planner ever walked the land. Maybe some considerations were made by the builder, and it was a done deal. We now have 40 plus town houses down the road, which was built so narrow that there is no roadside parking allowed down there. Our end of the road is a little wider so when people have a party they all park on our end. With the 40 plus houses and only one way out, you can imagine the traffic flow. As there is such limited access to the above planned development, I can see this happening there.

Now we get to the environmental impact. All the City can see is more houses, bringing in more taxes. However, you cannot keep on clearing woodlands in this manner. Out of one side of your mouths you say you are for preserving the environment, and out of the other you hand out building permits that should never be given. Believe me, there will be an enormous environmental impact. We, in this area, lost frogs, bats, quail, owls, swallows, ducks and geese, not to mention many beautiful old trees, native shrubs and brush that was home to multiple woodpeckers, wrens and so many other birds.

May we respectfully suggest that the City set aside this parcel of land as a Nature Reserve for future generations who will then be able to hear the bullfrogs, watch the woodpeckers make a nest, and so much more.

Sincerely, Anthony Dean.

Margaret J. Dean.

#13

10415 – 147th Avenue SE
Renton, WA 98059
January 3, 2014

Ms. Rocale Timmons
Senior Planner
City of Renton
1055 S. Grady Way
Renton, WA 98057

RECEIVED
JAN 6 2014
CITY OF RENTON
PLANNING DIVISION

RE: **PROJECT NUMBER**: LUA13-001572, ECF, PP

PROJECT NAME: The Reserve at Tiffany Park

Dear Ms. Timmons:

While looking at the Current Land Use site on the City of Renton web site, I came across the above listed plat. Since Wayne Potter is involved with KBS and Windstone, I decided to comment even though the comment period is over.

In the description it says: "The site is currently vacant with 1,305 significant trees and the applicant is proposing to retain 102 trees. (WOW!) It also says that this project is on hold.

According to the attached document – Renton's Tree Policy. I am sure that the developers will say that all the trees will need to come down because they will be in the foundation's foothold. So, why bother having a tree policy?

It takes years for trees to get to the size most trees are; the trees are the homes of wildlife and birds and enjoyment. What does this developer propose to do with the wildlife and birds that are displaced? And of course, the only mitigation is to replace them with trees barely big enough to be called trees. Maybe you should make the developer replace the removed trees with large fir trees and other "big trees".

As previously stated, I've watched Windstone go in on Nile. The developer allowed yellow water to flow down Greenes Stream to May Creek and didn't stop it. They allow dirt to stay on the road and flow into the nearby streams without cleaning it up. They "forget" to put in mitigation trees until caught in the act.

I hope that Renton really starts to protect the environment.

Thank you.

Sincerely,

Claudia Donnelly

Claudia Donnelly

From: Michael/Claudia Donnelly <thedonnellys@oo.net>
Subject: **Trees remaining in Renton**
Date: March 17, 2008 6:36:46 AM PDT

Begin forwarded message:

> **From:** "Jennifer Henning" <Jhenning@ci.renton.wa.us>
> **Date:** March 15, 2008 2:33:35 PM PDT
> **To:** "Michael/Claudia Donnelly" <thedonnellys@oo.net>
> **Subject: Re: Trees remaining in Renton**
>
> Hello Claudia,
> The revisions to the City's tree regulations became effective in September 2007. For projects subject to those regulations, a percentage of trees must be retained. Here is the code section (RMC4-4-130H):
>
> "H. PERFORMANCE STANDARDS FOR LAND DEVELOPMENT/BUILDING PERMITS:
> 1. Protected Trees – Retention Required: Trees shall be retained as follows:
>
> a. Damaged and Diseased Trees Excluded: Trees that are dangerous as defined in RMC 4-11-200, or are safety risks due to root, trunk, or crown structure failure shall not be counted as protected trees.
>
> b. Residential:
>
> i. RC, R-1, R-4 and R-8 Zones: Thirty percent (30%) of the trees shall be retained in a residential or institutional development.
>
> ii. R-10, R-14, RM-F, RM-T, RM-U and RMH: Ten percent (10%) of the trees shall be retained in a residential or institutional development.
>
> c. All Other Zones: Five percent (5%) of the trees located on the lot shall be considered protected and retained in commercial or industrial developments.
>
> d. Utility Uses and Mineral Extraction Uses: Such operations shall be exempt from the protected tree retention requirements of this Chapter if removal can be justified in writing and approved by the Reviewing Official.
>
> e. Replacement Requirements:
>
> i. When the required number of protected trees cannot be retained, new trees, with a two-inch (2") caliper or greater, shall be planted. The replacement rate shall be twelve (12) caliper inches of new trees to replace each protected tree removed.

ii. When a tree or tree cluster that is part of an approved tree retention plan cannot be retained, mitigation shall be required per subsection H1ei of this Section.

iii. Unless replacement trees are being used as part of an enhancement project in a critical area or buffer, they shall not consist of any species listed in RMC 4-4-130H7d.

f. Tree retention standards shall be applied to the net developable area. Land within critical areas and their buffers, as well as public rights-of-way, shall be excluded from the above calculation. If the number to be retained includes a fraction of a tree, any amount equal to or greater than one-half (1/2) tree shall be rounded up."

In recent years. and prior to this change in regulations, we were requiring 25% tree retention in residential areas, or replacement, generally at 2:1 with a minimum 2-inch caliper. A "protected tree" is considered to be a minimum of 6-inch caliper, as measured at 54 inches above grade. There are situations where extensive site grading requires that all trees be removed. In those cases planting of new trees is required.

Jennifer Toth Henning, AICP
Planning Manager
1055 South Grady Way
Renton, WA 98057
425.430.7286 (ph)
jhenning@ci.renton.wa.us

Michael/Claudia Donnelly <thedonnellys@oo.net> 03/12/08 10:45 AM

Jennifer:

I got a note this morning about some clear cutting next to Randy Corman's house. I thought -- that in 2007 before the POP election, Renton decided on an ordinance that would "save trees" in developments. In the past few months, along NE 4th -- a CAMWEST Development across from the QFC, there were alot of trees --- now there aren't any. Did Renton pass this "save a tree" in developments or not?

Thank you for any information you can provide.

Claudia Donnelly

#14

Rocale Timmons

From: Geoff and Meredith Erickson <geomer60@hotmail.com>
Sent: Tuesday, December 10, 2013 5:04 PM
To: Rocale Timmons
Subject: Tiffany Park Reserve/LUA13-001572, ECF, PP

Follow Up Flag: Follow up
Flag Status: Flagged

Reference plat # 2123059061, 2123059051, and 2123059044

Dear Senior Planner:

I oppose the development of these parcels for a number of reasons.

I believe that the notification process of residents was in error and that the response time must be extended. My reasoning is that the date of the letter and the delivery of the letter was delayed. Residents received the letter almost 1 week after the "date" of the letter.

I oppose the access with regards to ingress and egress. I strongly believe that the negative impact on the existing residents located on potential ingress and egress is excessive. The parcels have restricted access. This negative impact would be due to increased traffic flow. The increased traffic flow would also have a negative impact on pedestrian traffic.

I also oppose the square footage size of the dwelling in the proposed development. The reasoning is that the larger homes would most likely have a greater number of people residing in them. Generally, the more people residing in a home, the greater impact on increased traffic trips as more people would drive.

Thank you for your evaluation of my concerns.

Sincerely,

Geoff Erickson
1719 Pierce Ave SE
Renton 98058

#15

Wednesday, November 13, 2013

From: Robert Garlough
3203 SE 18th Street
Renton, WA 98058

To: City of Renton
Development Services Division
1055 South Grady Way
Renton, WA 98055

Subject: Comments to Proposed Land Use Action entitled, "Reserve at Tiffany Park"

I have reviewed the Subject "Proposed Land Use Action," as posted on the sign at the end of SE 18th Street. While I realize that the developer wants to maximize their profit from the land, I find it unacceptable for the City of Renton to allow plans that minimize the cost to the developer while showing little apparent regard for the impact to the safety and convenience of the surrounding community.

The plans show 98 houses, with all traffic funneled to only two access roads: one on 124th Place SE and another on SE 18th Street. Given the speed bumps to the South of the neighborhood and the fact that most people commute towards the city, I expect that the lion's share of the new traffic will travel on SE 18th Street - converting it from a safe and quiet cul-de-sac into a busy residential arterial street!

There is generally a 6% to 16% penalty in property values for living along a busy street. My neighbors and I have paid a lot of money to be on a cul-de-sac. Therefore, please consider mitigating the impact by allowing dramatically less houses in the 'Tiffany Park Reserve' development, or by requiring at least one more access road.

Please feel free to contact me with any questions or comments, or to notify me of any hearings for the subject development.

Thank you for your consideration.

Robert D. Garlough

Robert D. Garlough
bob@garlough.org
425-227-0090

#16

Rocale Timmons

From: Rocale Timmons
Sent: Thursday, December 12, 2013 6:06 AM
To: 'Larry Gorg'
Cc: Wayne Potter (wpotter@novastardev.com); Barbara Yarington (Barbara.Yarington@mainvuehomes.com) (Barbara.Yarington@mainvuehomes.com)
Subject: RE: Reserve at Tiffany Park

Hello Mr. Gorg,

Thank you for your email wherein you have raised concerns with respect to the Reserve at Tiffany Park Preliminary Plat (File No. LUA13-001572). This email will be added to the public record for consideration by the reviewing official. If you would like to be added as a party of record, and receive any future correspondence related to the application please provide your mailing address. I will address your concerns as they have been raised.

You have requested that the City delay the process in order to provide adequate time to digest the impact of the subject development. While the comment period, which ended on December 10, 2013 was not the end of the process for public participation we appreciate the neighborhoods concerns with respect to adequate time to comment given the fact that there was Holiday during the comment period. As a result the City will be extending the comment period and you should receive notice within the next couple of days as to the new deadline.

I do hope that you find the City of Renton's process to be inclusive. Public comments received during the comment period are used help City staff complete a comprehensive review which will continue over the next couple of months. The end of the public comment period does not preclude the public from participating in the remainder of the City's review. The City encourages public involvement throughout the entire process; an example being the Public Hearing which was tentatively scheduled for January 23, 2014, but will likely be rescheduled given the extension of the public comment period.

Please feel free to contact me should you have any other questions, would like supplemental materials from the application, or if would like to elaborate on your concerns. Again, thank you for your input.

Rocale Timmons
City of Renton - Current Planning
Senior Planner
1055 South Grady Way
Renton, WA 98057
Tel: (425) 430-7219

From: Larry Gorg [mailto:lpgorg@comcast.net]
Sent: Wednesday, December 11, 2013 7:26 PM
To: Rocale Timmons; Jan Illian
Subject: Reserve at Tiffany Park

Please add me to the "Person of Interest" contact list for the Reserve at Tiffany Park development. I would also like to make some comments on this development, but also feel this development is occurring to fast to digest the information. There are some concerns that need to be ironed out and feel that the deadline of December 10 was too short and should be extended so that we can properly digest what impact this new development will have on our neighborhood. I feel that we are being railroaded into accepting something that we do not fully understand and will have a negative impact on our standard of living.

Larry Gorg

#17

Mr. Robin Jones
3624 SE 19th CT
Renton, WA, 98058

CITY OF RENTON
RECEIVED
DEC 10 2013 4:16pm
BUILDING DIVISION

City of Renton
Development Planning
1055 South Grady Way
Renton, WA, 98055
ATTN: Rocale Timmons

Subject - Tiffany Park Reserve, LUA13-001572, ECF, PP

I am writing to raise concerns, during the public comment period about the Notice of Application that has been posted for the Tiffany Park Reserve. As a property owner living next door to this property, I strongly believe that I will be significantly impacted, both in terms of property value and quality of life, by the proposed design. My concerns with proposed plans are;

1. I have a general concern with the overall feasibility of the development plan presented. This area of land was purchased for use as a school in the early 1970 by the Renton School Board; we were advised in 2012 by the Renton School Board that a school could no longer be built on this site due to location and access issues and that the City of Renton zoning regulations no longer support construction of a school. It is unclear how the restrictions presented that precluded this possible school development do not somehow preclude the development of the proposed housing area. I believe that the proposed plan does not adequately address the earlier location and access concerns and that the initial approval of this development plan did not acknowledge these earlier issues.
2. I have a general concern with the overall plan presented for the entire area of the property for this type of development. This area of land has been undeveloped for close to forty years with no indication until last year that the Renton School Board had any intention of doing anything with it. Indeed most of the homeowners in the area, to include myself, assumed that this was an established green belt area and purchased our home with an understanding that this was so. Given the length of time that this area has been left free standing I believe that I have an implied and tacit expectation that this area should remain somewhat similar. I would argue that some given the length of time and continual use by the community of this area of land during these past forty years that some principles of the Prescriptive Easement apply in this situation.
3. I have a general concern with the overall plan; that the very limited layout options available to the developer, plus the need to recover the purchase and development costs, resulted in the developer forcing a high revenue generating, design into a very unsuitable space. The focus on making a high revenue generating development, fit the awkward lot size, within a limited time frame may have caused the developer not to acknowledge

some of the impacts their plan has on their neighbors and the surrounding community. This is reflected by the overall quality of the plan which has obvious, errors, duplications, and incorrect references (City of Kent). The impression is that the developer has shown little concern in checking or validating their material.

4. Specific Areas of concern

   a) Tree Retention - I don't believe that an honest effort has been undertaken by the developers to comply with the Tree Retention Requirement. A number of concerns within this area; the developer failed to try and meet the minimum number of trees that should be retained, the deduction of trees that are dead, diseased or dangerous seems proportionally high in comparisons to other development project, and it is unclear where in RMC 4-4-130 it allows for trees in proposed public streets to be deducted from the overall retention count.

   b) Wet lands – I don't believe that all the requirements around the wet lands within the proposed development plan have been correctly met. The roads in and out clearly encroach into the Wetland buffer areas in areas C and D. There appears to be minimal efforts to meet the buffer distances as defined by the distance. The roads could be slightly alters to avoid encroaching into the Wetland buffer. I believe a re-assessment of the wetland calculations and the buffer distances are needed to promote the purposed of using a buffer by distance as opposed to using Buffer averaging.

   c) Lot Size and Density – these are very small lots, significantly smaller that the surrounding houses which are 6,000 square feet or larger. Given the maturity of the existing community and the total enclosure of the proposed development area by existing homes the plans gives no consideration to any compatibility with the surrounding area, it is merely an effort to maximized the number of homes with the proposed area. I believe that greater efforts need to be made to harmonize with the surrounding community.

   A number of additional concerns within this area; it is unclear from the zone calculation sheet whether this includes the proposed roads, which still need right of way access, or not, it is unclear from the sheet whether the Critical Areas footage has been using the adjusted buffer distances proposed by the developer or the required distances, and what part of the 2.8 acre sensitive areas have been included in the critical area exclusion calculation 12, 056 number.

d) Line of sight. The current plan has a continual line of houses along the Mercer Island Pipeline Easement which will have direct line of site into the adjacent properties, to include mine. There appears to be no effort to manage direct lines of sight in to our properties or provide any degree of screening. I would request that this concern be reviewed and addressed.

e) Right of Way access and Easements – Unclear how the plan can be considered acceptable without a clear understanding of whether the developer have acquired the need access and easement to build roads and plan development with both the City of Mercer and Cedar River Pipeline Organizations. Would request initial approval be demonstrated from both these parties prior to any site plan approval.

f) Environmental Check list – some concerns with portions of this initial review. Key concern would be around the Wetland report, some of the property measurements were conducted at the end of the year 2012, following one of the driest summers on record. The perception by the community is that this was deliberately by the developer to minimize the wetland impact results. I have concerns that the results accurately reflect the normal condition of this area around the ground and surface water assessment.

A couple of concerns in this area, given the time that the area has been undeveloped, I don't believe that due investigation has occurred effort around whether there are any threatened/endangered animals and whether this site is part of a migration route.

g) Traffic and Access Issues – Fundamental concerns in this area is that all traffic into area is being routed thru local access streets no major thru of fairs. This is a significant increase of traffic in around key areas to include an Elementary school, recreational areas, and walking trails.

I can be reached at (425) 228 4396 or RobinHJ@msn.com to schedule hearing times.

Thank you

Robin Jones

#18

Lee & Adrienne Lawrence
1721 Pierce Avenue S.E.
Renton, WA
Tel. 425-277-1302

City of Renton
Rocale Timmons, Senior Planner
CED – Planning Division
1055 South Grady Way
Renton, WA 98057

RECEIVED
DEC 09 2013
CITY OF RENTON
PLANNING DIVISION

Subject: Tiffany Park Reserve/LUA13-001572 ECF, PP

Mr. (s) Timmons:

Lee and I would like to start out by requesting that you extend the deadline for comments on this Project by three days, as we did not receive your notification until November 29th. Your notice is dated November 26, a Tuesday before the Thanksgiving Holiday and it should have been apparent that the recipients would not receive the notice three days after it was dated. By extending the date, it allows the affected residents to make comments on this important issue that affects all of us in this area.

The following are our concerns along with others about the development as it is proposed:

The impact of the proposed development will have a negative impact on all residences surrounding it due to

1) Increased traffic
2) Loss of a buffer the current woods provide
3) Increase in students for the already filled to capacity schools
4) Noise during construction

The impact to the environment is also significant, as there are wetlands, old growth and various wildlife in these woods.

In my opinion, the wetlands are larger than the developer has outlined. We challenge the classification of those wetlands. We request that an assessment by an independent agency be performed as to the amount, size and classification of those wetlands.

We oppose the storm water detention vault.

There are several old growth trees in these woods and they should be preserved. We request an independent study of the trees. We also dispute the number of trees quoted in your notice.

There is a considerable amount of wildlife in these woods, i.e. deer, bobcats, mountain beavers, pileated woodpeckers, hawks and more. We request an explanation on what is planned for the displaced wildlife. Furthermore, we also request that no trees be cut during nesting season.

What is the City of Renton planning to do about the displaced rat population? They will all migrate to the neighboring properties.

Are there mines under this property and if so, what impacts will that have?

We request that the developer leave a buffer of trees that are already lining the Mercer Island Pipeline – this would provide a visual buffer for the existing houses east of that pipeline.

We challenge and oppose the proposed access extended from 124th Place S.E., crossing the Cedar River Pipeline. This access would increase traffic in an established neighborhood and would require the cutting of several beautiful old trees.

We believe that the studies provided by the developer are outdated and incorrect as the last wetland study was done after 2 months of draught. I request a copy of all the studies.

We challenge the City of Renton's statement that this development will not have a significant environmental impact. This development will have a huge impact on the environment and the neighbors surrounding the woods. Many of us have purchased our homes because of the woods and the buffer they provide from other neighborhoods. This development will reduce the value of our homes and the quality of our lives. I request that the city of Renton deny this development or at least reduce the amount of houses to be built.

I request that you change the time of the public hearing on January 23rd from 10 am to a time after 4 pm so everyone can attend; the decisions being made will affect our homes, our neighborhood and lives in general – so a schedule should be set so that those of us that work can also attend.

Respectfully Submitted,

Lee & Adrienne Lawrence

Lee & Adrienne Lawrence

#19 ✓

Rocale Timmons

From:	Adrienne Lawrence <varetta1@comcast.net>
Sent:	Tuesday, December 10, 2013 4:33 PM
To:	Rocale Timmons
Cc:	varetta1@comcast.net
Subject:	Concrete Wall barrier in Greenbelt Area
Importance:	High
Follow Up Flag:	Follow up
Flag Status:	Flagged

Hello,
My name is Adrienne Lawrence and I sent a letter previously regarding the changes being proposed in the Tiffany Park Area. I have owned my home for over 33 years, purchased before my home was even built and had the opportunity to change my house plans. When my house was being sold by the builder in 1980, the information that was included referenced the greenbelt behind the homes in this area and the back of my home directly faces across from the greenbelt. When I sit on my deck or have friends and family over, the greenbelt is beautiful greenery with trees that lends a semblance of tranquility in our neighborhood. Most of our children have grown up playing in this area as well; it would be quite devastating to lose this view and on top of that having to swallow the insult of seeing the value of our property decrease. I wonder what this builder would think if a builder was coming into his neighborhood and bringing upheaval and destruction.

I just found out that the builder is proposing putting up a concrete wall, which when I sit out on my deck is what I will be seeing each and every time. Again, who would want to purchase a home with a view of a concrete wall? I urge you to not allow this to happen in our neighborhood...my husband, Lee and I are very much against this concrete wall barrier that is being proposed leave things as they are.

I urge you to listen to those of us that have a stake in this upheaval. Thank you for your consideration in reference to this issue.

Sincerely,
Lee & Adrienne Lawrence
1721 Pierce Avenue SE
Renton, Wa 98058

#20 ✓

Dear Senior Planner:

I would like to go on record as being opposed to the development of the Tiffany Park Reserve as currently planned. The cutting of the woods, grading of the land, building of roads, utilities and residences would have a negative impact on wildlife, the environment, property values, neighbors and the citizens of Renton.

Some, but not all, of the negative aspects are listed here:

1. Reduction of wildlife habitat. These woods are home to Bobcats, many birds including owls and the occasional eagle, deer, raccoons and others. The development would reduce or eliminate their presence. It could also result in an increase certain pests such as rats and mice in the area as a result of the reduction in predators.

2. Impact to the environment by the removal of trees. Taking down 21 acres of forest would reduce the production of oxygen and the consumption of the greenhouse gas carbon dioxide. The wetlands would be affected, even if buffered, by the change in water flows from grading the land and the introduction of impermeable surfaces. And pollution of the air and water would increase.

3. Reduction of property values. The development of the site would reduce the value of the surrounding residences in several ways. The view from each house would go from one of peaceful nature to rows of closely spaced houses and fences. The noise levels would increase with all the additional dogs, cars and yard maintenance. The general traffic level would increase, and the houses on the two entrance roads would see a large increase.

4. Reduction of the quality of living here. The presence of the woods provides a great amount of pleasure to the people that live next to them. Even people that are not direct neighbors benefit by having a nice place to walk and play. The site serves as a kind of undeveloped park for the area.

5. Possible damage to surrounding properties. The woods on the site serve as a windbreak for a large number of surrounding properties. A lot of these

properties have a significant number of large trees on them. Removal of the woods will expose tress to more wind during storms, which may lead to property damage from falling trees.

I submit that there has not been enough study and evaluation of the sale of the property and the development plan. I would like to see alternative uses for the property proposed and evaluated. My proposal would be to keep it as an undeveloped park owned by the city and kept as a refuge for wildlife and recreation. Thank you for your consideration.

Doug, Elizabeth and Michael Frisch

1717 Pierce Ave SE

Renton, WA 98058

425-228-2346

We agree with the above letter.

ALBERT and SHARON OCHO
1711 PIERCE AV SE
RENTON, WA. 98058
425 255 0225

From: **rentonwa1@gmail.com**
Subject: Fwd: woods development Frisch's letter to city planner
Date: December 8, 2013 at 12:11 PM
To: Sharon slo1111@live.com, Geoff and Meredith geomer60@hotmail.com

This is a great letter - maybe you can use it as a templet?
The more people comment on this the better we have a chance to make a difference, so, please take the time and write something?
You can also email your comment to rtimmons@rentonwa.gov - this was in the notice you got from the city

Renate

Sent from my iPad

Begin forwarded message:

> **From:** Renate Beedon <rentonwa1@gmail.com>
> **Date:** December 7, 2013, 11:52:29 AM PST
> **To:** Douglas Frisch <frisch1@hotmail.com>
> **Subject: Re: woods development Frisch's letter to city planner**
>
> Wow - great letter, Doug, thank you!
>
>> On Sat, Dec 7, 2013 at 11:17 AM, Douglas Frisch <frisch1@hotmail.com> wrote:
>> Here is what I am mailing to the city planner today. Thank you for all the great effort.
>>
>> **To: Timmons, Senior Planner**
>> **Planning Division**
>> **1055 Grady Way**
>> **Renton 98057**
>>
>> **Reference plat # 2123059061, 2123059051, and 2123059044**

#2 ✓

December 4, 2013

R. Timmons, Senior Planner, Planning Division, City of Renton

Re: Tiffany Park Reserve Development

I live in the area that will be impacted by this development. Given what us homeowners have been through to this point, I find it highly unlikely that ANYONE would ever listen to us but since this is the only forum there is to express our American God given right, here I am.....

I have lived in my home for 33 years. The woods that I have enjoyed all these years have been sold by the school district (for which a developer was already in the wings if you look at the date the district first decided to sell the property, the date the preliminary plat was filed, etc.....) And the recent letter sent out told us there would be a public hearing on 1/23 at 10am. Those of us that work Mon – Fri cannot attend this scheduled hearing. Sadly.

Developing that land to the extent that is planned is going to impact our values. The housing market has not rebounded to a degree that we can afford to take a hit for losing the benefit of those woods for those of us that live on the greenbelt. Each and every day I look out there, walk out there and see all the wildlife that lives there – it is absolutely heartbreaking that all that life is being displaced. Where will that wildlife go? And then where will the vermin go? Them leaving does not break my heart but they will be forced towards our homes. ....and what about all the trees that will have to come down and all the wetlands areas that are not showing on your map (the soil study done in July of 2012 was done after it had not rained for 45 days).........As old as some of those trees are, there is going to be an impact for those of us that have trees along the other side of the greenbelt. Do you have any idea how far those tree roots travel for trees that are that high? Trust me – I do – I had to replace my water line because of them. Cutting those trees down is going to be killing the trees on our property due to the root system and that leaves our property susceptible to damage.

Has anyone considered traffic? Do you realize what is going to happen to the traffic around here? Our streets up here are small as it is and with the number of homes that are planned, there will be a very negative impact on the traffic increase, street parking......... too many homes, too large of homes all brings far too much traffic to absorb up here.

There is no room in the neighborhood schools for more students..........at the November meeting, a school district rep (John Knutson) stated students would have to be bussed out of the area to accommodate any increase in the student population. Am I the only one that does not make sense to? Granted I no longer have school age kids, but were I parent of a school age child, I would have a big issue with that.

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DEC 06 2013
CITY OF RENTON
PLANNING DIVISION

I am opposed to every aspect of this development due to the impacts it will have on all those things mentioned above. It's just too much and somewhere along the line all this developing of raw, beautiful, bountiful, fruitful and perfectly pristine land has got to stop.

There is clearly nothing that is going to stop this development. It will likely happen no matter what we say or do. Been there and done that with the school district last year and I'm clearly still bitter about that. With that said, the trees that are directly on the greenbelts need to be retained with some sort of a buffer. This needs to be done to protect the current homeowners' views, way of life, etc.....as well as giving the "new" homeowners some semblance of the neighborhood they are invading. I doubt they want to look out their window and see us anymore than we want to see them. The prospect of having to keep my blinds closed does not appeal to me and I doubt it would appeal to any of you either. That is the least the developer can do for taking away what has been a very significant part of our lives.

Thank you

Barbara Smith
3619 SE 19th Ct
Renton WA 98058

Email: barbiandlance@live.com

#22 ✓

From the desk of Rosemary Quesenberry
3609 Southeast 18 Court
Renton, WA . 98058

RE: development of plat # 2123059061, 2123059051, and 2123059044

I oppose the magnitude of development of the above plats of land as proposed by ...

The impact of developing this property to the magnitude desired by the developer would have an extreme negative impact on the existing neighborhoods and the environment.

I am requesting a formal wetland delineation. I dispute the size of the wetlands as indicated in the proposed development plans. I believe that the wetland area is considerably underestimated in size as well as locations within the site. This area absorbs and retains a great amount of water. An evaluation of the amount of wetland vegetation, hydrology, and hydraulic soil should be evaluated by a scientist.

A large buffer zone should be imposed to protect unique large trees and other vegetation that protect the wetlands. The wetland areas have old cedar trees that are essential to the preservation of the wetland area. I dispute the number of trees counted within the site. The number of trees and their age have been underestimated.

The technical soil sample evaluation was completed in September 2012. This work was completed after a record "no measurable rainfall" for a period of over 60 days. The results do not reflect the true condition of the soil. I request a second soil evaluation be completed.

I request an evaluation the aquifers that flow within the proposed development s site. Aquifers and recharge areas are essential to our environment and must be identified and protected.

I am requesting a wildlife area habitat evaluation be completed on the site.
I encourage that development be delayed until the bird hatching period is over.
This area is abundant with varies types of wildlife.

The increased automobile traffic will have a negative impact on the existing neighborhoods based on limited access to the property. The access to the property greatly increases the traffic flow in existing residential streets. There is no thoroughfare to accommodate the increased traffic flow.
Pedestrian traffic would also be negatively impacted by the large amount of automobile traffic. I encourage a traffic mitigation measures be designed by a specialist to address the situation.

For the reasons listed above, I oppose the magnitude of this plat proposal.

Cordially,

Rosemary Quesenberry

Rosemary Quesenberry

#23

1819 Ferndale Ave SE
Renton, WA 98058
December 2, 2013

Rocale Timmons
Senior Planner
City of Renton
1055 South Grady Way
Renton, WA 98057

Dear Ms. Timmons,

Please consider the following comments regarding the "Reserve at Tiffany Park" development (LUA13-001572, ECF, PP):

We appreciate the passages enabling pedestrian access between houses to the pipeline right-of-way along the east edge of the development. Many current residents walk or jog along that right-of-way. It is to the benefit of all to have "good guys" out there to discourage vandalism.

Some of the local pipeline right-of-ways are just fenced corridors and those fences are covered with graffiti and shed/garage windows are often broken. Right-of-ways with softer edges - that is, fence lines with native plant boundaries outside the fence both look better and suffer less damage. A good example of such planting is the eastern half mile of Puget Dr SE as well as the water tower at Puget Dr SE and Edmonds Ave SE. Little maintenance is required, the property looks nice and attracts little attention from hoodlums.

Perhaps the "Reserve" would benefit from such a soft edge along its eastern boundary.

Thank you for your attention,

Greg & Jenny Swanson

Greg & Jenny Swanson

#24

Rocale Timmons

From: Karen Walter <KWalter@muckleshoot.nsn.us>
Sent: Tuesday, December 10, 2013 10:14 AM
To: Rocale Timmons
Subject: RE: Tiffany Park LUA13-001572, ECF, PP, Notice of Application and Proposed Determination of Non-Significance
Attachments: Landscape Ecotoxicology of Coho Salmon Spawner Mortality in Urban watersheds.pdf; copper toxicity_visibility vulnerability juv coho salmon predation by cutthroat trout_McIntyre et al 2012.pdf; Copper_effects_on_Salmonids_-_Abstracts_C A _Woody1.pdf

Follow Up Flag: Follow up
Flag Status: Flagged

Rocale,
Thank you for assisting us with getting the referenced documents in the SEPA materials for the proposed Tiffany Park Reserve subdivision project (referenced above). We have reviewed these materials and offer the following comments in the interest of protecting and restoring the Tribe's treaty-protected fisheries resources:

Our primary concern with this project is the proposed "basic treatment" of stormwater generated by the site that will discharge to Ginger Creek and eventually the Cedar River. We understand that the project's stormwater treatment approach meet the 2009 King County Surface Water Design Manual (KCSWDM). However as the stormwater will eventually discharge to salmon-bearing waters, we recommend that enhanced stormwater treatment, including oil/water separators be required for this project. Enhanced stormwater water quality treatment is needed to maximize the removal of PAHs and heavy metal pollutants found in stormwater that are harmful to salmon in downstream receiving waters. Additional information about these pollutants and impacts to salmon, including a risk assessment for Puget Sound Coho, can be found in the attached documents.

We appreciate the opportunity to review this proposal and look forward to the Renton's responses. Please let me know if you have any questions.

Thank you,
Karen Walter
Watersheds and Land Use Team Leader

Muckleshoot Indian Tribe Fisheries Division
Habitat Program
39015 172nd Ave SE
Auburn, WA 98092
253-876-3116

From: Rocale Timmons [mailto:RTimmons@Rentonwa.gov]
Sent: Tuesday, December 10, 2013 7:47 AM
To: Karen Walter
Subject: RE: Tiffany Park LUA13-001572, ECF, PP, Notice of Application

Hello Karen,

They sent the FTP site while I was out yesterday.

Please see their attached email.

If you have problems with the site let me know and I will try and attach the reports via email.

From: Karen Walter [mailto:KWalter@muckleshoot.nsn.us]
Sent: Monday, December 09, 2013 11:55 AM
To: Rocale Timmons
Subject: Tiffany Park LUA13-001572, ECF, PP, Notice of Application
Importance: High

Hi Rocale,
I am checking in to see if you had a chance to get the Stormwater Tech Report, Wetland Determination and Tree Protection Plan that we would like to review before comments are due on this project tomorrow, 12/10.

Thank you!
Karen Walter
Watersheds and Land Use Team Leader

Muckleshoot Indian Tribe Fisheries Division
Habitat Program
39015 172nd Ave SE
Auburn, WA 98092
253-876-3116

Copper: Adverse Effects on Salmonids

Scientific Abstracts and References

Compiled by: Dr. Carol Ann Woody
Fisheries Research and Consulting
Anchorage, AK carolw@alaskalife.net
fish4thefuture.com

The following information was collected from recent peer reviewed scientific publications. The full text of each article is available from the journal and publisher cited. Cu = copper. * Indicates annotations by C. Woody for clarification or explanation. Questions or comments or criticisms greatly appreciated. For information on the importance of olfaction to fish see the Salmon Ecology 101 Fact Sheet.

Pyle, GG, and RS Mirza. 2007. Copper-impaired chemosensory function and behavior in aquatic animals. Human and Ecological Risk Assessment. 13 (3): 492 – 505.

Abstract: Chemosensation is one of the oldest and most important sensory modalities utilized by aquatic animals to provide information about the location of predators, location of prey, sexual status of potential mates, genetic relatedness of kin, and migratory routes, among many other essential processes. The impressive sophistication of chemical communication systems among aquatic animals probably evolved because of the selective pressures exerted by water as a "universal solvent." Impairment of chemosensation by toxicants at the molecular or cellular level can potentially lead to major perturbations at higher levels of biological organization. We have examined the consequences of metal-impaired chemosensory function in a range of aquatic animals that represents several levels of a typical aquatic ecosystem. In each case, low, environmentally relevant metal concentrations were sufficient to cause chemosensory dysfunction. Because the underlying molecular signal transduction machinery of chemosensory systems demonstrates a high degree of phylogenetic conservation, we speculate that metal-impaired chemosensation among phylogenetically disparate animal groups probably results from a common mechanism of impairment. We propose developing a chronic chemosensory-based biotic ligand model (BLM) that maintains the advantages of the current BLM approach, while simultaneously overcoming known difficulties of the current gill-based approach and increasing the ecological relevance of current BLM predictions.

'Safe' heavy metals hit fish senses. 18:16 09 April 2007. NewScientist.com news service. Aria Pearson

Pollution far below the level seen as dangerous for aquatic life has nevertheless dramatically altered animal behaviour in North American lakes. Heavy metals are knocking out the sense of smell in organisms from bacteria to fish. Even we may not be immune.

Nathaniel Scholz, at the Northwest Fisheries Science Center in Seattle, Washington, and colleagues found that salmon lose their sense of smell if there are even low levels of copper in the water they are swimming in. The fish could die as a result, because they cannot smell chemicals that would warn of a nearby predator.

All over the world, storm water run-off shuttles heavy metals such as copper and zinc from industry, mines and built-up areas into natural water courses. The concentrations are generally low - too low for polluters to bother about, or so many of them seem to have thought. "Now we're going after [this] 'So what?' question," says Scholz.

Scholz's team kept young coho salmon in tanks with different concentrations of copper for 3 hours, then measured their movements when a drop of salmon skin extract was added to the water. In the wild, the skin would be a cue that a predator may have injured a fish nearby.

Unexposed salmon stopped swimming, sank to the bottom of the tank and kept still - typical tactics for avoiding predators. But fish exposed to concentrations of copper as low as 2 parts per billion (ppb) just stopped for a few seconds, or merely slowed down, while fish exposed to 10 or more ppb didn't notice the cue at all (*Environmental Science and Technology*, DOI: 10.1021/es062287r).

The US Environmental Protection Agency has set the maximum safe level of copper for aquatic life at 13 parts per billion, well above that needed to wipe out the salmon's ability to sense chemical cues. Yet Greg Pyle, at Nipissing University in North Bay, Ontario, Canada, has found chemosensory problems at three levels of the food chain at or below 5 ppb, the limit set by Ontario's water quality standards. "The phenomenon is ubiquitous," he says.

Leeches lost their ability to smell food, zooplankton were unable to evade predators, and fathead minnows couldn't recognize their eggs: the fish ate them instead of protecting them. The contamination in these lakes is much too weak to kill these organisms outright, Pyle says, yet their populations are suffering.

Metals may have the same effect in humans. The makers of the cold remedy Zicam, which contains zinc, recently settled out of court for $12 million with people who reported losing their sense of smell after spraying the product into their noses. The company maintains the remedy is safe. Studies have not been conducted to test whether zinc destroys human sensory abilities, but given what's happening in aquatic ecosystems, Pyle believes it could. "Don't squirt metals up your nose," he says. "That would be my advice'.

Sandahl, JF, DH Baldwin, JJ Jenkins and NL Schlotz. 2007. A sensory system at the interface between urban stormwater runoff and salmon survival. Environ. Sci. Technol. 41:2998-3004.

Abstract: Motor vehicles are a major source of toxic contaminants such as copper, a metal that originates from vehicle exhaust and brake pad wear. Copper and other pollutants are deposited on roads and other impervious surfaces and then transported to aquatic habitats via stormwater runoff. In the western United States, exposure to non-point source pollutants such as copper is an emerging concern for many populations of threatened and endangered Pacific salmon (*Oncorhynchus spp.*) that spawn and rear in coastal watersheds and estuaries. To address this concern, we used conventional neurophysiological recordings to investigate the impact of ecologically relevant copper exposures (0-20 µg/L for 3 h) on the olfactory system of juvenile coho salmon (*O. kisutch*). These recordings were combined with computer-assisted video analyses of behavior to evaluate the sensitivity and responsiveness of copper-exposed coho to a chemical predation cue (conspecific alarm pheromone). The sensory physiology and predator avoidance behaviors of juvenile coho were both significantly impaired by copper at concentrations as low as 2 µg/L. Therefore, copper-containing stormwater runoff from urban landscapes has the potential to cause chemosensory deprivation and increased predation mortality in exposed salmon.

Baldwin, DH, JF Sandahl, JS Labenia, and NL Schloz. 2003. Sublethal effects of copper on coho salmon: impacts on nonoverlapping

receptor pathways in the peripheral olfactory nervous system. Environmental Toxicology and Chemistry. 10:2266–2274.

Abstract: The sublethal effects of copper on the sensory physiology of juvenile coho salmon (*Oncorhynchus kisutch*) were evaluated. In vivo field potential recordings from the olfactory epithelium (electro-olfactograms) were used to measure the impacts of copper on the responses of olfactory receptor neurons to natural odorants (L-serine and taurocholic acid) and an odorant mixture (L-arginine, L-aspartic acid, L-leucine, and L-serine) over a range of stimulus concentrations. Increases in copper impaired the neurophysiological response to all odorants within 10 min of exposure. The inhibitory effects of copper (1.0–20.0 mg/L) were dose dependent and they were not influenced by water hardness. Toxicity thresholds for the different receptor pathways were determined by using the benchmark dose method and found to be similar (a 2.3–3.0 mg/L increase in total dissolved copper over background). Collectively, examination of these data indicates that copper is broadly toxic to the salmon olfactory nervous system. Consequently, short-term influxes of copper to surface waters may interfere with olfactory-mediated behaviors that are critical for the survival and migratory success of wild salmonids.

Hansen, JA, JD Rose, RA Jenkins, KG Gerow, HL Bergman. 1999. Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*) exposed to copper: neurophysiological and histological effects on the olfactory system. Environmental Toxicology and Chemistry. 9:1979-1991.

Abstract: Olfactory epithelial structure and olfactory bulb neurophysiological responses were measured in chinook salmon and rainbow trout in response to 25 to 300 μg copper (Cu)/L. Using confocal laser scanning microscopy, the number of olfactory receptors was significantly reduced in chinook salmon exposed to greater than or equal to 50 μg Cu/L and in rainbow trout exposed to greater than or equal to 200 μg Cu/L for 1 h. The number of receptors was significantly reduced in both species following exposure to 25 μg Cu/L for 4 h. Transmission electron microscopy of olfactory epithelial tissue indicated that the loss of receptors was from cellular necrosis. Olfactory bulb electroencephalogram (EEG) responses to 10(-3) M L-serine were initially reduced by all Cu concentrations but were virtually eliminated in chinook salmon exposed to greater than or equal to 50 μg Cu/L and in rainbow trout exposed to greater than or equal to 200 μg Cu/L within 1 h of exposure. Following Cu exposure, EEG response recovery rates were slower in fish exposed to higher Cu concentrations. The higher sensitivity of the chinook salmon Olfactory system to Cu-induced histological damage and neurophysiological impairment parallels the relative species sensitivity observed in behavioral avoidance experiments. This difference in species sensitivity may reduce the survival and reproductive potential of chinook salmon compared with that of rainbow trout in Cu-contaminated waters.

Dethloff, GM, D Schlenk, JT Hamm, and HC Bailey. 1999. Alterations in physiological parameters of rainbow trout (*Oncorhynchus mykiss*) with exposure to copper and copper/zinc mixtures. Ecotoxicology and Environmental Safety. 42(3):253-264.

Abstract: Rainbow trout (*Oncorhynchus mykiss*) were exposed to sublethal concentrations of copper (Cu, 14 mu g/liter or parts per billion) and zinc (Zn, 57 and 81 mu g/liter or ppb) for a 21-day period. The four treatments included a control, a Cu control, a Cu and low-Zn treatment and a Cu and high-Zn treatment. Selected parameters [e.g., hemoglobin (Hb), hematocrit (Hct), plasma glucose, lactate and cortisol, differential leukocyte count, respiratory burst, tissue metal concentrations, hepatic metallothionein (MT), brain acetylcholinesterase (AChE)] mere evaluated at 2, 7, 14, and 21 days of exposure, Whole blood and

plasma parameters mere not altered by exposure to metals. The percentage of lymphocytes was consistently decreased in the three metal treatments, while percentages of neutrophils and monocytes mere increased. Respiratory burst activity was elevated in all metal treatments. Gill Zn concentration was highly variable, with no significant alterations occurring. Gill Cu concentration was elevated above control levels in all metal treatments, Gill Cu concentration in the two Cu/Zn treatments was also elevated above levels in the Cu control. Hepatic metal concentrations and MT levels were not altered from control values. Measurements of brain AChE indicated an elevation in this parameter across metal treatments. In general, alterations in physiological parameters appeared to be due to Cu, with Zn having no interactive effect.

Hansen JA, Lipton J, Welsh PG. 2002. Environmental toxicology and chemistry. 21 (3): 633-639.

Abstract: Bull trout (Salvelinus confluentus) were recently listed as threatened in the United States under the federal Endangered Species Act. Past and present habitat for this species includes waterways contaminated with heavy metals released from mining activities. Because the sensitivity of this species to copper was previously unknown, we conducted acute copper toxicity tests with bull (*bull trout are an endangered type of charr like Dolly Varden) and rainbow trout (*Oncorhynchus mykiss*) in side-by-side comparison tests. Bioassays were conducted using water at two temperatures (8 degrees C and 16 degrees C) and two hardness levels (100 and 220 mg/L as $CaCO_3$). At a water hardness of 100 mg/L both species were less sensitive to copper when tested at 16 degrees C compared to 8 degrees C. The two species had similar sensitivity to copper in 100-mg/L hardness water, but bull trout were 2.5 to 4 times less sensitive than rainbow trout in 220-mg/L hardness water. However, when our results were viewed in the context of the broader literature on rainbow trout sensitivity to copper, the sensitivities of the two species appeared similar. This suggests that adoption of toxicity thresholds that are protective of rainbow trout would be protective of bull trout; however, an additional safety factor may be warranted because of the additional level of protection necessary for this federally threatened species.

Brix KV, DeForest DK, Adams WJ. 2001. Assessing acute and chronic copper risks to freshwater aquatic life using species sensitivity distributions for different taxonomic groups. Environmental Toxicology and Chemistry. 20 (8): 1846-1856.

Abstract: Using copper as an example, we present a method for assessing chemical risks to an aquatic community using species sensitivity distributions (SSDs) for different taxonomic groups. This method fits probability models to chemical exposure and effects data to estimate the percentage of aquatic species potentially at risk and expands on existing probabilistic risk assessment methodologies. Due to a paucity of chronic toxicity data for many chemicals, this methodology typically uses an acute-chronic ratio (ACR) to estimate the chronic effects distribution from the acute effects distribution. We expanded on existing methods in two ways. First, copper SSDs were developed for different organism groups (e.g., insects, fish) that share similar sensitivities or ecological functions. Integration of exposure and effects distributions provides an estimate of which organism groups may be at risk. These results were then compared with a site-specific food web, allowing an estimation of whether key food web components are potentially at risk and whether the overall aquatic community may be at risk from the perspective of ecosystem function. Second, chronic SSDs were estimated using the relationship between copper ACRs and acute toxicity (i.e., the less acutely sensitive a species, the larger the ACR). This correction in the ACR removes concerns previously identified with use of the ACR and allows evaluation of a significantly expanded chronic data set with the same approach as that for assessing acute risks.

Goldstein, JN, DF Woodward, and AM Farag. 1999. Movement of adult Chinook salmon during spawning migration in a metals-contaminated system, Coeur d'Alene River, Idaho. *Transactions of the American Fisheries Society* 128:121–129.

Abstract: Spawning migration of adult male chinook salmon *Oncorhynchus tshawytscha* was monitored by radio telemetry to determine their response to the presence of metals contamination in the South Fork of the Coeur d'Alene River, Idaho. The North Fork of the Coeur d'Alene River is relatively free of metals contamination and was used as a control. In all, 45 chinook salmon were transported from their natal stream, Wolf Lodge Creek, tagged with radio transmitters, and released in the Coeur d'Alene River 2 km downstream of the confluence of the South Fork and the North Fork of the Coeur d'Alene River. Fixed telemetry receivers were used to monitor the upstream movement of the tagged chinook salmon through the confluence area for 3 weeks after release. During this period, general water quality and metals concentrations were monitored in the study area. Of the 23 chinook salmon observed to move upstream from the release site and through the confluence area, the majority (16 fish, 70%) moved up the North Fork, and moved up the North Fork, and only 7 fish (30%) moved up the South Fork, where greater metals concentrations were observed. Our results agree with laboratory findings and suggest that natural fish populations will avoid tributaries with high metals contamination.

Dethloff, GM, and HC Bailey. 1998. Effects of Copper on Immune System Parameters of Rainbow Trout (Oncorhynchus mykiss). Environmental Toxicology and Chemistry. 17(9):1807-1814.

Abstract: Agricultural, urban, industrial, and mining sources release metals into waterways. The effects of sublethal concentrations of metals on integrated physiological processes in fish, such as immunocompetency, are not well understood. The objective of this study was to determine the physiological effects of a range of sublethal copper concentrations (6.4, 16.0, and 26.9 mu g Cu/L) on Shasta-strain rainbow trout (*Oncorhynchus mykiss*) exposed in soft water. Trout were sampled after 3, 7, 14, and 21 d of exposure to copper. The percentage of monocytes was consistently elevated at 26.9 mu g Cu/l, and the percentage of lymphocytes was decreased. A consistent increase in the percentage of neutrophils occurred at 26.9 and 6.4 mu g Cu/l. Respiratory burst activity was decreased for all concentrations at all sampling days, but a significant reduction occurred only at 14 and 21 d of exposure to copper. B-like cell proliferation was decreased(*In short, all this means that the immune system of fish was affected by Cu exposure. Woody) by exposure to the higher copper concentrations. Proliferation results, however, had high variability. T-like cell proliferation and phagocytosis were not altered. Hepatic copper concentration was consistently elevated in trout exposed to 26.9 mu g Cu/L; no correlation was found between hepatic copper concentration and the Immune system responses investigated. Consistent alterations in immunological parameters suggest that these parameters could serve as indicators of chronic metal toxicity in natural systems.

Buhl, KJ and SJ Hamilton. 1991. Relative sensitivity of early life stages of arctic grayling, coho salmon, and rainbow trout to nine inorganics. Ecotoxicology and Environmental Safety. 2:184-197.

Abstract: The acute toxicity of nine inorganics associated with placer mining sediments to early life stages of Arctic grayling (*Thymallus arcticus*), coho salmon (*Oncorhynchus kisutch*), and rainbow trout (*O. mykiss*) was determined in soft water (hardness, 41 mg liter^{-1} $CaCO_3$) at 12°C. The relative toxicities of the inorganics varied by four orders of magnitude; from most toxic to least toxic, the rank order was cadmium,

silver, mercury, nickel, gold, arsenite, selenite, selenate, and hexavalent chromium. In general, juvenile life stages of the three species tested were more sensitive to these inorganics than the alevin life stage. Among juveniles, no single species was consistently more sensitive to the inorganics than another; among alevins, Arctic grayling were generally more sensitive than coho salmon and rainbow trout. Based on the results of the present study, estimated no-effect concentrations of arsenic and mercury, but not cadmium, chromium, gold, nickel, selenium, or silver, are close to their concentrations reported in streams with active placer mines in Alaska. Thus, arsenic (as arsenite(III)) and mercury may pose a hazard to Arctic grayling and coho salmon in Alaskan streams with active placer mines.

Saiki, MK, DT Castleberry, TW May, BA Martin, and FN Bullard. 1995. Copper, cadmium, and zinc concentrations in aquatic food-chains from the upper Sacramento River (California) and selected tributaries. Archives of Environmental Contamination and Toxicology. 29(4):484-491.

Abstract: Metals enter the Upper Sacramento River above Redding, California, primarily through Spring Creek, a tributary that receives acid-mine drainage from a US EPA Super-fund site known locally as Iron Mountain Mine. Waterweed (*Elodea canadensis*) and aquatic insects (midge larvae, Chironomidae; and mayfly nymphs, *Ephemeroptera*) from the Sacramento River downstream from Spring Creek contained much higher concentrations of copper (Cu), cadmium (Cd), and zinc (Zn) than did similar taxa from nearby reference tributaries not exposed to acid-mine drainage. Aquatic insects from the Sacramento River contained especially high maximum concentrations of Cu (200 mg/kg dry weight in midge larvae), Cd (23 mg/kg dry weight in mayfly nymphs), and Zn (1,700 mg/kg dry weight in mayfly nymphs). Although not always statistically significant, whole-body concentrations of Cu, Cd, and Zn in fishes (threespine stickleback, *Gasterosteus aculeatus*; Sacramento sucker, *Catostomus occidentalis*; Sacramento squaw-fish, *Ptychocheilus grandis*; and chinook salmon, *Oncorhynchus tshawytscha*) from the Sacramento River were generally higher than in fishes from the reference tributaries.

Baatrup, E. Structural and Functional-Effects of Heavy-Metals on the Nervous-System, Including Sense-Organs, of Fish. Comparative Biochemistry and Physiology C-Pharmacology Toxicology & Endocrinology. 1991; 100(1-2):253-257.

Abstract: Today, fish in the environment are inevitably exposed to chemical pollution. Although most hazardous substances are present at concentrations far below the lethal level, they may still cause serious damage to the life processes of these animals. Fish depend on an intact nervous system, including their sense organs, for mediating relevant behavior such as food search, predator recognition, communication and orientation. Unfortunately, the nervous system is most vulnerable and injuries to its elements may dramatically change the behavior and consequently the survival of fish.

Heavy metals are well known pollutants in the aquatic environment. Their interaction with relevant chemical stimuli may interfere with the communication between fish and environment. The affinity for a number of ligands and macromolecules makes heavy metals most potent neurotoxins. The present Mini-Review highlights some aspects of how trace concentrations of mercury, copper and lead affect the integrity of the fish nervous system; structurally, physiologically and biochemically.

Oregon study shows copper from brake pads affects salmon
CORVALLIS, Ore., Oregon State University issued the following news release:

Copper deposited on roads by the wearing of brake pads is transported in runoff to streams and rivers, where it may play a key role in increasing predation of threatened and endangered salmon throughout California and the Pacific Northwest. According to a study released this week in Environmental Science and Technology, levels of copper as low as 2 parts per billion have a direct impact on the sensory systems of juvenile coho salmon. The skin of juvenile salmon is equipped with a special kind of warning system, said Nat Scholz, a researcher at the Northwest Fisheries Science Center, a branch of the National Oceanic and Atmospheric Association (NOAA) Fisheries Service. When a salmon is attacked by a predator, a chemical cue is released from the skin that signals danger to nearby fish. These fish smell the predation cue and take behavioral measures to avoid being eaten.

Oregon State University researchers working with scientists from NOAA Fisheries, found that fish exposed to low, environmentally realistic levels of copper had an impaired sense of smell and were less responsive to the chemical alarm signal. At elevated concentrations of copper, these predator avoidance behaviors were largely abolished.

Copper naturally occurs in aquatic environments at trace amounts as a background element. However, fluctuations due to run-off from storm events can increase the level of copper in the water from close to zero to more than 60 parts per billion in some instances, said Jason Sandahl, who co-authored the study while working as an OSU doctoral research assistant at the NOAA research laboratory.

'There is a fine line between active copper uptake and copper toxicity,' said Sandahl. 'We see problems when copper is pulsed into the water, temporarily elevating the copper higher than the natural background level. The olfactory, or scent, neurons are not able to maintain the normal regulation of copper, and the neurons are either disrupted or killed.' Salmon are known to avoid environmental gradients of copper, such as those created by point-source discharges. However, copper in stormwater is a diffuse form of non-point source pollution, and it is unlikely that juvenile fish could reduce their exposure through avoidance behaviors, said the researchers.

As a result of automobile braking and exhaust, higher levels of copper contamination have been observed in streams close to roads and highways. Building materials and certain pesticide formulations are also important sources of copper in western landscapes, said Scholz.

Recent monitoring of northern California streams following storm events found dissolved copper levels averaging 15.8 parts per billion per liter of water. Salmon exposed to copper at concentrations well below this average showed significant impairment to both their sensory physiology and predator avoidance behavior, said Sandahl, whose work on the study was funded in part by a National Institute of Environmental Health Sciences grant to OSU. The work was also supported by NOAA's national Coastal Storms Program.

Since the duration of storm events that cause elevated levels of copper in streams can be relatively short, investigators exposed juvenile coho salmon to copper for only a few hours. In earlier studies they found the onset of copper neurotoxicity to salmon olfactory systems occurs within a matter of minutes. Loss of sensory function is likely reversible, but may take hours or days of the fish being in clean water, said the researchers. If copper exposures are high enough to cause the death of olfactory sensory neurons, it will take several weeks to months for the fish to regenerate new neurons and recover.

The levels of copper contaminant used in the study were at or below current federal regulatory guidelines for heavy metals, said Jeff Jenkins, an environmental toxicologist in OSU's College of Agricultural Sciences. 'It's just like they were poisoned,' said Jenkins. 'Of all the chemicals we have looked at, this effect was clearly happening at levels well below the current copper standards for water quality. It raises the question of whether the current standards are as protective as we thought.'

The current study is an example of how contaminants can disrupt the chemical ecology of aquatic organisms. In the case of salmon, a sublethal loss of sensory function may increase predation mortality in urbanizing watersheds. The influence of copper on predator-prey interactions is the focus of ongoing research, with the eventual aim of linking individual survival to the productivity of wild salmon populations, said Scholz.

Though the study was conducted on juvenile salmon, the results are applicable to fish species in urban watersheds worldwide, said the researchers. Dissolved copper has been shown to affect the olfactory systems of chinook salmon, rainbow trout, brown trout, fathead minnow, Colorado pikeminnow and tilapia.

Barry, KL, JA Grout, CD Levings, BH Nidle, and GE Piercy. 2000. Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound, British Columbia. Can. J. Fish. Aquat. Sci. 57: 2032–2043.

Abstract: The abandoned copper mine at Britannia Beach, British Columbia, has been releasing acid mine drainage (AMD) into Howe Sound for many years. To assess the impacts of AMD on juvenile salmonids in the Britannia Creek estuary, we compared fish abundance, distribution, and survival at contaminated sites near the creek with uncontaminated areas in Howe Sound. Water quality near Britannia Creek was poor, particularly in spring when dissolved Cu exceeded1.0 mg·L–1 and pH was less than 6. Beach seine surveys conducted during April–August 1997 and March–May1998 showed that chum salmon (*Oncorhynchus keta*) fry abundance was significantly lower near Britannia Creek mouth(0–1.2·100 m–2) than in reference areas (11.5–31.4·100 m–2). Laboratory bioassays confirmed that AMD from Britannia Mine was toxic to juvenile chinook (*Oncorhynchus tshawytscha*) and chum salmon (96-h LC50 = 0.7–29.7% in freshwater and 12.6–62.2% in 10 ppt water). Chinook salmon smolts transplanted to surface cages near Britannia Creek experienced100% mortality within 2 days. These results demonstrated that juvenile salmonids are vulnerable to AMD from Britannia Creek: their abundance peaks during spring when Cu concentrations are highest and toxicity is greatest in surface freshwater, which matches their preferred vertical distribution.

Eisler, R. COPPER HAZARDS TO FISH, WILDLIFE, AND INVERTEBRATES:
A SYNOPTIC REVIEW. U.S. Geological Survey, Laurel, MD 20708

Excerpt specific to fish:

Fishes Adverse sublethal effects of copper on behavior, growth, migration, and metabolism occur in representative species of fishes at nominal water concentrations between 4 and 10 µg/L. In sensitive species of teleosts, copper adversely affects reproduction and survival from 10-20 µg Cu/L (Hodson et al. 1979; Table 5). Copper exerts a wide range of physiological effects in fishes, including increased metallothionein synthesis in hepatocytes, altered blood chemistry, and histopathology of gills and skin (Iger et al. 1994). At environmentally realistic concentrations, free copper adversely affects resistance of fishes to bacterial diseases; disrupts migration (that is, fishes avoid copper-contaminated spawning grounds); alters locomotion through hyperactivity; impairs respiration; disrupts osmoregulation through inhibition of gill Na^+-K^+-activated ATPase; is associated with tissue structure and pathology of kidneys, liver, gills, and other hematopoietic tissues; impacts mechanoreceptors of lateral line canals; impairs functions of olfactory organs and brain; and is associated with changes in blood chemistry, enzyme activities, and corticosteroid metabolism (Hodson et al. 1979).

Copper-induced cellular changes or lesions occur in kidneys, lateral line, and livers of several species of marine fishes (Gardner and LaRoche 1973). Copper-induced mortality in teleosts is reduced in waters with high concentrations of organic sequestering agents and in genetically resistant species (Hodson et al. 1979). At pH values less than 4.9 (that is, at pH values associated with increased aluminum solubility and toxicity), copper may contribute to the demise of acid-sensitive fishes (Hickie et al. 1993). Copper affects plasma Na^+ and gill phospholipid activity; these effects are modified by water temperature and hardness (Hansen et al. 1993). In red drum, copper toxicity is higher at comparatively elevated temperatures and reduced salinities (Peppard et al. 1991). Copper is acutely toxic to freshwater teleosts in soft water at concentrations between 10 and 20 µg/L (NAS 1977). In rainbow trout, copper toxicity is markedly lower at high salinities (Wilson and Taylor 1993). Comparatively elevated temperatures and copper loadings in the medium cause locomotor disorientation of tested species (Kleerekoper 1973). Copper may affect reproductive success of fish through disruption of hatch coordination with food availability or through adverse effects on larval fishes (Ellenberger et al. 1994). Chronic exposure of representative species of teleosts to low concentrations (5 to 40 µg/L) of copper in water containing low concentrations of organic materials adversely affects survival, growth, and spawning; this range is 66 to 120 µg Cu/L when test waters contain enriched loadings of organic materials (Hodson et al. 1979). Larval and early juvenile stages of eight species of freshwater fishes are more sensitive to copper than embryos (McKim et al. 1978) or adults (Hodson et al. 1979). But larvae of topsmelt (*Atherinops affinis*) are increasingly sensitive to copper with increasing age. Topsmelt sensitivity is associated with increasing respiratory surface area and increasing cutaneous and branchial uptake of copper (McNulty et al. 1994). Sublethal exposure of fishes to copper suppresses resistance to viral and bacterial pathogens (Rougier et al. 1994) and, in the case of the air-breathing catfish (*Saccobranchus fossilis*), affects humoral and cell-mediated immunity, the skin, and respiratory surfaces (Khangarot and

Tripathi 1991). Rainbow trout exposed to 50 µg Cu/L for 24 h—a sublethal concentration—show degeneration of olfactory receptors that may cause difficulties in olfactory-mediated behaviors such as migration (Klima and Applehans 1990). The primary site of sublethal copper toxicity in rainbow trout is the ion transport system of the gills (Hansen et al. 1993). Dietary copper is more important than waterborne copper in reducing survival and growth of larvae of rainbow trout (Woodward et al. 1994). Simultaneous exposure of rainbow trout to dietary and waterborne copper results in significant copper assimilation. Diet is the main source of tissue copper; however, the contribution of waterborne copper to tissue burdens increases as water concentrations rise (Miller et al. 1993). Rate and extent of copper accumulations in fish tissues are extremely variable between species and are further modified by abiotic and biological variables. Copper accumulations in fish gills increase with increasing concentrations of free copper in solution, increasing dissolved organic carbon (DOC), and decreasing pH and alkalinity (Playle et al. 1993a, 1993b). Starved Mozambique tilapia accumulate significantly more copper from the medium in 96 h than did tilapia fed a diet containing 5.9 mg Cu/kg DW ration (Pelgrom et al. 1994). The bioconcentration factor for whole larvae of the fathead minnow was 290 after exposure for 30 h, but only 0.1 in muscle of bluegills after 660 h (USEPA 1980). Prior exposure of brown bullheads (*Ictalurus nebulosus*) to 83 sublethal copper concentrations for 20 days before exposure to lethal copper concentrations produces higher copper concentrations in tissues of dead bullheads than in those not previously exposed; however, the use of tissue residues is not an acceptable autopsy procedure for copper (Brungs et al. 1973). Rising copper concentrations in blood plasma of catfish (*Heteropneustes fossilis*) seem to reflect copper stress, although the catfish appear outwardly normal. Plasma copper concentrations of catfish increase from 290 µg Cu/L in controls at start to 380 µg Cu/L in survivors at 72 h (50% dead); a plasma copper concentration of 1,060 µg Cu/L at 6 h is associated with 50% mortality (Banerjee and Homechaudhuri 1990). In rainbow trout, copper is rapidly eliminated from plasma; the half-time persistence is 7 min for the short-lived component and 196 min for the long-lived component (Carbonell and Tarazona 1994). Attraction to waters containing low (11 to 17 µg/L) concentrations of copper occurs in several species of freshwater teleosts, including goldfish (*Carassius auratus*) and green sunfish (*Lepomis cyanellus*); however, other species, including white suckers (*Catostomus commersonii*), avoid these waters (Kleerekoper 1973). In avoidance/attraction tests, juvenile rainbow trout avoided waters containing 70 µg Cu/L but were significantly attracted to water containing 4,560 µg Cu/L; a similar pattern was observed in tadpoles of the American toad, *Bufo americanus* (Birge et al. 1993). Copper concentrations in the range of 18 to 28 µg/L interfere with bluegill growth and prey choice (Sandheinrich and Atchison 1989). Copper interferes with the ability of fish to respond positively to L-alanine, an important constituent of prey odors; concentrations as low as 1 µg Cu/L inhibit this attraction response in some species (Steele et al. 1990). Increased tolerance to copper was observed in fathead minnows after prolonged exposure to sublethal concentrations, but tolerance was not sustained on removal to clean water. Copper tolerance in fathead minnows is attributed to increased production of metallothioneins (Benson and Birge 1985). Copper tolerance in rainbow trout seems dependent on changes in sodium transport and permeability (Lauren and McDonald 1987a).

Further Reading

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Ecological Applications, 22(5), 2012, pp. 1460–1471

Low-level copper exposures increase visibility and vulnerability of juvenile coho salmon to cutthroat trout predators

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Abstract. Copper contamination in surface waters is common in watersheds with mining activities or agricultural, industrial, commercial, and residential human land uses. This widespread pollutant is neurotoxic to the chemosensory systems of fish and other aquatic species. Among Pacific salmonids (*Oncorhynchus* spp.), copper-induced olfactory impairment has previously been shown to disrupt behaviors reliant on a functioning sense of smell. For juvenile coho salmon (*O. kisutch*), this includes predator avoidance behaviors triggered by a chemical alarm cue (conspecific skin extract). However, the survival consequences of this sublethal neurobehavioral toxicity have not been explored. In the present study juvenile coho were exposed to low levels of dissolved copper (5–20 μg/L for 3 h) and then presented with cues signaling the proximity of a predator. Unexposed coho showed a sharp reduction in swimming activity in response to both conspecific skin extract and the upstream presence of a cutthroat trout predator (*O. clarki clarki*) previously fed juvenile coho. This alarm response was absent in prey fish that were exposed to copper. Moreover, cutthroat trout were more effective predators on copper-exposed coho during predation trials, as measured by attack latency, survival time, and capture success rate. The shift in predator–prey dynamics was similar when predators and prey were co-exposed to copper. Overall, we show that copper-exposed coho are unresponsive to their chemosensory environment, unprepared to evade nearby predators, and significantly less likely to survive an attack sequence. Our findings contribute to a growing understanding of how common environmental contaminants alter the chemical ecology of aquatic communities.

Key words: alarm behavior; coho salmon; copper; cutthroat trout; olfaction; predation; skin extract; sublethal; survival.

Introduction

Various forms of water pollution are known to interfere with chemical communication in aquatic habitats (Sutterlin 1974). There are senders and receivers of chemical signals both within and among species in aquatic communities, and certain contaminants are directly toxic to the olfactory, mechanosensory, or gustatory sensory neurons of receivers. This form of sublethal ecotoxicity has been termed info-disruption (Lurling and Scheffer 2007) because it diminishes or distorts the sensory inputs that convey important information about an animal's surrounding environment. Contaminant-exposed receivers thereby respond inappropriately (or not at all) to cues that signal the proximity and status of predators, mates, food, and other factors that can influence growth, survival, distribution, or reproduction.

Manuscript received 7 November 2011; revised 26 March 2012; accepted 29 March 2012. Corresponding Editor: K. Tierney.

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One of the most extensively studied examples of info-disruption is the neurotoxicity of dissolved copper to the peripheral olfactory system of fish (Tierney et al. 2010). Olfactory receptor neurons are located in the epithelium of the olfactory rosette, within the nasal cavity. Cilia containing odor receptors extend from the apical surfaces of olfactory neurons into the nasal cavity, separated from ambient waters by a thin layer of mucous. Olfactory receptor neurons are continuously exposed to ambient waters and are therefore highly vulnerable to dissolved toxicants in aquatic habitats.

Copper is a widely occurring pollutant in association with diverse human activities, including agricultural, industrial, commercial, and residential land uses. For example, copper is used in various agriculture and homeowner pesticide formulations, in building materials, as an antifoulant in hull paints for vessels, and in motor vehicle friction materials (i.e., brake pads). As a consequence, copper is commonly transported to aquatic systems in land-based stormwater runoff (Davis et al. 2001). Copper contamination is also associated with hard rock mining and municipal wastewater discharges.

Similar to fish mechanosensory receptor neurons (i.e., lateral line; Linbo et al. 2006), olfactory receptor neurons undergo cell death in response to dissolved copper concentrations above approximately 20 μg/L (Julliard et al. 1996, Hansen et al. 1999). At lower concentrations in the 2–20 μg/L range, dissolved copper reversibly inhibits the physiological responsiveness of olfactory receptor neurons in a concentration-dependent manner (Baldwin et al. 2003, Sandahl et al. 2004). The loss of sensory function occurs rapidly, within the first few minutes of copper exposure (Baldwin et al. 2003). In most fish species that have been studied to date, peripheral sensory neurons do not acclimate to copper during exposures lasting days (Julliard et al. 1996, Linbo et al. 2006) or weeks (Saucier et al. 1991, Saucier and Astic 1995).

Chemical signals of predation risk are an ecologically important category of olfactory information for fish (Wisenden 2000, Ferrari et al. 2010). For many species (Chivers and Smith 1998), including juvenile salmonids, an olfactory alarm cue released via mechanical tearing of the skin (e.g., during a predation event) triggers predator avoidance behaviors by nearby conspecifics. Juvenile salmon and trout, for example, become motionless in response to the alarm cue (Brown and Smith 1997, Berejikian et al. 1999, Scholz et al. 2000). This reduces their visibility and corresponding vulnerability to attack by motion-sensitive predators such as piscivorous fishes and birds (Webb 1986, Martel and Dill 1995). Numerous studies have demonstrated a survival benefit for alarm-cue-responsive prey (Mirza and Chivers 2001, 2003, Chivers et al. 2002).

Previous studies have shown that peripheral olfactory toxicity and diminished sensory responsiveness correspond to a disruption in alarm behaviors in copper-exposed fish (Beyers and Farmer 2001, Sandahl et al. 2007). For individual juvenile coho salmon (*Oncorhynchus kisutch*), loss of alarm behavior triggered by an ecologically relevant olfactory alarm cue is directly correlated with loss of olfactory function at copper exposures ranging from 2 to 20 μg/L (Sandahl et al. 2007).

Copper's effect on chemical communication in aquatic systems has broad implications for the chemical ecology and conservation of aquatic species and communities. In the case of salmon, subtle but important impacts on sensory physiology and behavior at the juvenile life stage could increase predation mortality and thus increase losses from wild salmon populations, many of which remain at historic lows in large river basins throughout the western United States (Good et al. 2005). Conversely, improving water quality conditions (i.e., by reducing copper loading) could potentially improve juvenile survival and abundance, thereby enhancing ongoing efforts to recover depressed stocks. However, the cascading effects of copper across biological scales, from salmon physiology and behavior to predator–prey interactions and survival, have not been empirically determined.

Here we explored the influence of environmentally relevant copper exposures on juvenile coho salmon (see Plate 1) predator avoidance and survival during encounters with coastal cutthroat trout (*O. clarki clarki*). Cutthroat trout are visual foragers (Henderson and Northcote 1985, Mazur and Beauchamp 2003) that commonly prey on juvenile salmon in stream, lake, and nearshore marine habitats (Nowak et al. 2004, Duffy and Beauchamp 2008). We used a range of sublethal copper exposures (5–20 μg/L) and a duration (3 h) previously shown to impair both peripheral olfaction and alarm behavior in juvenile coho (Sandahl et al. 2007). In a subset of trials, predators were also exposed to dissolved copper (10 μg/L for 3 h).

Methods and Materials

Animals

Juvenile coho.—

1. *Behavior experiments.*—In 2007, wild juvenile coho salmon were collected as needed by seining a side channel of Big Beef Creek at the University of Washington's Big Beef Creek Research Station (Seabeck, Washington, USA). Coho were maintained on well water (Table 1) in indoor raceways under natural light regime and fed pellets daily (1–2 mm extruded; Silver Cup Fish Feed, Murray, Utah, USA). Coho grew slightly throughout the experimental period, from April–May (39–49 mm total length [TL], $\bar{x} = 42.8$, SD = 3.3, $n = 13$) to June–July (36–60 mm TL, $\bar{x} = 48.7$, SD = 5.6, $n = 79$).

2. *Predation experiments.*—In 2008, juvenile coho were produced from eggs fertilized at the Big Beef Creek Research Station. Hatchlings were maintained outdoors in 1-m^3 net pens suspended in a 5 m diameter circular tank continuously supplied with well water. One net pen of juveniles (approximately 1000 fish) provided the experimental prey. Coho were fed pellets daily. Coho grew slightly throughout the experimental period; random samples in April–May were 30–40 mm TL ($\bar{x} = 36.2$, SD = 2.5, $n = 24$) and in June–July were 35–46 mm TL ($\bar{x} = 41.3$, SD = 2.7, $n = 64$). During predation trials, there was a significantly higher attack rate on the larger coho in June–July compared to those used in April–May ($t_{29} = -2.136$, $P = 0.041$), likely related to the slightly larger size and therefore visibility of coho in the second set of predation trials. Other predator prey metrics were not affected ($P = 0.084$–0.625).

Cutthroat trout.—

1. *Behavior experiments (response to upstream predator).*—During April 2007, wild cutthroat trout (sizes 178–245 mm TL, $\bar{x} = 205$, SD = 18, $n = 16$) for use as predators were obtained from Big Beef Creek in smolt traps at a weir operated by Washington Department of Fish and Wildlife. Predators were maintained outdoors in flow-through circular holding tanks supplied with well water. On experimental days, predators were fed one juvenile coho each. Other days, predators were fed one fish each every other day. Predators were divided

TABLE 1. Conventional water chemistry characteristics, including total organic carbon (TOC), for source (well) water at the Big Beef Creek Research Station (Seabeck, Washington, USA).

Parameter	Units	D.L.	N	Mean	SE
pH			11	7.5	0.3
Alkalinity	mg/L $CaCO_3$	1.0	11	46.7	0.7
Hardness	mg/L $CaCO_3$	1.0	11	56.0	0.0
Bicarbonate	mg/L	1.0	11	46.7	0.7
Calcium	mg/L	0.05	11	18.00	0.00
Potassium	mg/L	0.10	11	0.50	0
Magnesium	mg/L	0.05	11	2.67	0.03
Sodium	mg/L	0.05	11	11.00	0.00
Chloride	mg/L	1.0	11	15.7	0.3
Sulfate	mg/L	1.0	11	2.0	0
TOC	mg/L	0.1	7	0.07†	0.01
0 Cu	μg/L	0.04	6	0.16	0.04
5 Cu	μg/L	0.04	2	4.54	0.07
10 Cu	μg/L	0.04	6	9.21	0.13
10 Cu‡	μg/L	0.04	8	8.94	0.54
10 Cu§	μg/L	0.04	4	8.06	0.34
20 Cu	μg/L	0.04	2	17.25	0.55

Notes: Also shown are measured copper concentrations for the different exposures; copper measurements are for exposure aquaria unless otherwise noted. D.L. stands for instrument detection limit.

† An eighth sample had anomalously high TOC (0.68 mg/L) and was excluded

‡ Experimental arenas for predator + prey trials.

§ Predator holding tanks for predator + prey trials.

randomly into four groups of four. On experimental days, predators within a group were randomly assigned to one of four arenas. Groups were rotated such that each predator was exposed to each treatment.

2. *Predation experiments.*—During April 2008, wild cutthroat trout for use as predators (sizes 150–215 mm TL, $\bar{x} = 183$, SD = 18, $n = 32$) were again obtained from Big Beef Creek and divided into three groups: groups 1 and 2 contained 8 predators each and were used in predation trials, while group 3, containing 16 predators, was held in reserve. Between the first set of predation trials (15–30 May) and the second set (25 June–3 July), predators in groups 1 and 2 were replaced with inexperienced fish from group 3. On experimental days, predators in Group 1 and Group 2 were fed one juvenile coho each during the predation trial. On other days, fish in all three groups were fed one fish each, every other day. For six days prior to collecting experimental data, predators were trained daily by simulating the experimental sequence. Trout were acclimated in the tank behind the divider for 1 h. The divider was then lifted, allowing the predators to locate, attack, and consume up to two prey fish.

Experimental arenas and alarm cue delivery

Behavior experiments with upstream predator.—Outdoor raceways (0.84 m width) were divided into segments (1.2 m long) with steel mesh barriers to create one experimental arena per raceway. A PVC sheet (1/16 inch [~0.16 cm]; Calsak Plastics, Kent, Washington, USA) subdivided by gridlines (5 cm^2) was placed at the bottom of each arena. Well water flowed into the raceway (2 L/s) from an underwater pipe upstream of the arena. A standpipe downstream of the arena maintained a water depth of 25 cm. Dividers partitioned each arena into an upstream predator-containing compartment (46 × 84 cm) and an adjacent downstream compartment containing prey (76 × 84 cm). Dividers were frames (13 cm wide) constructed from PVC sheets (1/16 inch) and covered with window screen.

Well water or skin extract was delivered to the prey compartment through evenly spaced holes in a tube (Tygon tubing, 1/4 inch outer diameter [~0.63 cm]) crossing the upstream divider, approximately 5 cm below the surface. Even dispersion was confirmed visually by dye tests. A three-way valve connected to a syringe allowed for injection of water or water plus alarm odor from outside the visual field of the fish.

Predation experiments.—Circular fiberglass tanks (bottom diameter = 130 cm, height = 90 cm) were used as experimental arenas. Gridlines were drawn at 5-cm intervals on the tank bottom to track fish location via video. An external standpipe maintained water depth (30 cm, 400 L). A sheet of PVC (90 × 60 cm) suspended vertically was used to divide cutthroat trout predators into a small sub-area (34 L) of the arena during acclimation. Juvenile coho prey were introduced into the arena and allowed to acclimate within a clear acrylic cylinder (25 cm inner diameter, 38 cm tall; U.S. Plastic Corp, Lima, Ohio, USA). The acclimation chamber was placed in one of the quadrants opposite the predator divider, within 15 cm from the tank edge. Predator dividers and acclimation chambers were attached by rope to overhead pulleys so they could be gently raised without the observer coming into view of the fish.

Skin extract was introduced to the prey acclimation chamber via Tygon® tubing just below the water surface connected to a three-way valve fitted with two syringes outside the tank. The skin extract solution was immediately flushed from the line with well water (60 mL).

Skin extract alarm cue

An alarm cue-containing skin extract from juvenile coho was prepared as previously described (Sandahl et al. 2007).

Behavior experiments with upstream predator.—In each flow-through arena, 1 mL of concentrated skin extract (160 cm^2 juvenile coho skin/L) was diluted in 50 mL of well water to a final concentration of 2 cm^2/L. This solution was introduced over 60 s into an average flow of 2 L/s for an exposure of approximately 1×10^{-3} $cm^2 \cdot L^{-1} \cdot s^{-1}$. Pilot trials confirmed a behavioral reaction to the alarm cue at this diluted concentration ($\bar{x}$ activity reduction = 51%, SD = 15%, $n = 8$).

Predation experiments.—Initial range-finding tests indicated that 2×10^{-5} cm^2 of homogenized skin extract per liter of water was the minimum concentration to evoke an alarm response ($\bar{x}$ activity reduction = 77%, SD = 24%, $n = 4$). This agrees closely with previously published thresholds for conspecific skin extract evoking predator avoidance behavior in salmonids (1.85×10^{-5} cm^2/L in *O. mykiss* [Mirza and Chivers 2003]; 2×10^{-5} cm^2/L in *O. kisutch* [Sandahl et al. 2007]). In static arenas, diluted skin extract (1 cm^2/L) was prepared daily from a frozen aliquot of concentrated skin extract (22 cm^2/L). At the end of the 15-min prey acclimation, 257 μL of diluted skin extract in 50 mL of well water was injected into the prey acclimation chamber (12.9 L) for a final skin concentration of 2×10^{-5} cm^2/L. Dye tests indicated that injected water did not diffuse from the acclimation chamber prior to the chamber being lifted from the experimental arena.

Copper exposures

Juvenile coho were exposed to dissolved copper prior to experimental trials. Exposures took place in 30-L glass aquaria wrapped in black plastic and supplied with an airstone. Aquaria were filled with 15 L of well water (controls) or well water containing varying copper concentrations (conventional water quality parameters shown in Table 1). Copper was added to the aquaria just prior to the onset of the 3-h exposures. Copper chloride stock solution (0.15 g Cu/L) was diluted to achieve nominal concentrations of 0, 5, 10, or 20 μg/L.

Experimental sequence

Behavior experiments with upstream predator.—Individual predators were placed in the predator compartment of each arena, upstream of the prey compartment, the evening before a trial and allowed to acclimate (>13 h). The following morning, juvenile coho (1 prey/predator) were exposed to either well water or well water containing 20 μg/L copper for 3 h. They were then transferred to the prey compartment of the experimental arena (one prey per arena) and allowed to acclimate for 30 min prior to the injection of stimulus solutions (water or water plus skin extract).

Predation experiments.—The timeline for predation trials is delineated in Table 2. For trials in which only juvenile coho prey were exposed to copper, predators (two per arena) were acclimated behind the divider during the last hour of the 3-h prey exposure interval. Exposed prey were then transferred to the acrylic chamber (two fish per arena) for 15 min, an interval brief enough to minimize olfactory recovery in clean water and yet long enough to produce reliably robust control activity (swimming speed ~5 cm/s). Filming began at the time of prey transfer. Following prey acclimation, skin extract was administered and given 30 s to disperse (verified with dye tests) before the chamber was gently lifted and removed from the experimental arena. Thereafter, predators were released from their enclosure. Two consecutive sets of trials using a different group of predators were run each day, and the arenas were drained and filled between sets.

Table 2. Predation trial timeline.

Timeline	Duration	Event
−3 h 15min	3 h	prey exposure
−1 h 0 min	1 h	predator acclimation
−15 min	15 min	prey acclimation
0 min	10 s	skin extract injected
30 s	10 s	prey released
50 s	5 s	predators released

For trials in which both prey and predators were exposed to copper, both exposures were for 3 h, including acclimation time in the experimental arena. Predators were exposed to copper for 2 h in their holding tanks followed by a 1-h exposure in the experimental arena. Prey were exposed to copper in the exposure aquarium for 2.75 h. This was followed by 15 min in the acclimation chamber of the experimental arena.

Water chemistry analyses

Conventional water quality parameters and total organic carbon (TOC) were measured in water samples collected in 2008 between 20 May and 3 July. This interval spans most of the experimental period (16 May–3 July). Concurrently, dissolved copper (DCu) concentrations were measured in 28 samples that were representative of the different copper exposures. For conventional parameters, samples were stored at 4°C in polyethylene bottles until analysis by standard methods at an EPA-certified laboratory (AmTest Laboratories; Redmond, Washington, USA). Samples for TOC were stored in glass vials at −20°C until analysis by combustion catalytic oxidation/NIDR method with a Shimadzu TOC-VCSH (University of Washington, Oceanography Technical Services, Seattle, Washington, USA). Samples for dissolved copper were stored at 4°C for up to 72 h prior to analysis by inductively coupled plasma mass spectrometry (Frontier Global Sciences, Seattle, Washington, USA).

The well water at BBC used in all experiments had low ion and organic carbon content (Table 1), which is similar to Pacific Northwest streams west of the

Cascades (e.g., Fig. 2 in McIntyre et al. 2008). The background copper concentration was very low (mean of 0.16 μg/L) and samples from copper exposures were 81–91% of nominal concentrations.

Video data acquisition

The four experimental arenas were sheltered outdoors beneath a wooden scaffolding to which cameras and pulleys were attached. The stand was covered by blue tarps to prevent direct lighting. Prey acclimation and predation trials were filmed with digital video cameras (SONY Exwave HAD SSC-M383) fitted with auto-iris lenses (2M-2812A, F1.4 DC AutoIris, 1/3″ varifocal 28–12 mm, angle of view 95.6–22.1 degrees; Sony, Tokyo, Japan) mounted over each arena. Video footage for the four concurrent trials were recorded on a digital video recorder (Pro 8-CH DVR; SecurityCameraWorld.com, Cooper City, Florida, USA) at 30 frames per second (FPS).

Data analysis

Coho activity.—

1. *Behavior experiments.*—Following the 30-min acclimation, the activity of juvenile coho was quantified for 5 min by measuring swimming speed, approximated by the sum of vertical and horizontal line crossings on the 5-cm^2 grid of the prey compartment.

2. *Predation experiments.*—We quantified prey activity after coho were released from the acclimation chamber, during the 10 s prior to releasing the predators. Average swimming speed across the 10-s period was determined by tracking each prey fish in two-dimensional space with image analysis software. Using Quicktime Pro (version 7.6; Apple, Cupertino, California, USA), video was exported as an image sequence at 1 frame per second. In Image J, the position (x, y) of each prey fish was tracked between images, converting changes in position into swimming speed (cm/s) by standardizing the pixels to the bottom tank dimensions (software *available online*).[4] We assumed that movement between frames was linear.

For most prey pairs (69/76), the two fish were equally active, and we averaged the swimming speed of the two prey each second. In the remaining 10% of cases, one prey was significantly more active (Kolmogorov-Smirnov distribution test, $P < 0.05$), and the more active prey was attacked first in seven of the eight cases. For these pairings, we used only the activity record for the more active prey in calculating prey activity.

Predation trial metrics.—Predator–prey interactions were analyzed from video recordings of each predation trial. Only attacks and captures of the first prey of the prey pair were quantified. Metrics were time to first attack (δA), time to capture (δC), time between first attack and capture (δC − δA), number of attacks (A), and attack frequency (attacks per second during attack period; A/[δC − δA]). For each copper concentration and predator exposure combination, 16 predation trials were conducted for a total of 112 data trials. Not all metrics could be quantified for all trials.

Statistical analyses

Coho prey activity.—For the experiments in 2007, a two-factor ANOVA was used to explore whether copper exposure (0 vs. 20 μg/L) affected the behavioral response (activity level) to predation risk (no risk, upstream predator, upstream predator plus skin extract). Simple main effects analysis used a Bonferroni adjustment for multiple comparisons. For 2008, single-factor ANOVA was used to test the effect of the various copper treatments on prey activity in the combined presence of predators and skin extract. Dunnett's post-hoc was used to compare activity in the copper treatments to the control treatment. Statistical analyses were conducted in SPSS 16.0 for MacIntosh (IBM, Armonk, New York, USA).

Predator–prey interactions.—Data for predator–prey interactions were not normally distributed and were positively skewed, being bounded by zero. Log-transformation resulted in normally distributed δA, δC, and A, which were analyzed by ANOVA followed by Dunnett's post-hoc for comparing copper treatments to controls. Log-transformation did not normalize δC − δA and attack frequency. Differences in central tendency of δC − δA and attack frequency were tested by Kruskal-Wallis nonparametric multiple comparison. For the separate set of predation trials in which predators were also exposed to copper, Tukey's post-hoc test was used following the ANOVA to compare among the three treatments (controls, prey exposed to 10 μg/L copper, predator + prey exposed to 10 μg/L copper).

The relationship between capture success probability (capture on first attack) and copper treatment was tested by linear regression of the natural log of the odds ratio for capture success weighted by sample size. This method transforms curvilinear data in a probability distribution to a linear function of the independent variable. We transformed capture success probability at each copper concentration to the log$_e$ odds ratio (OR) as follows:

$$\log_e(\mathrm{OR}) = \ln\left(\frac{\mathrm{CSR}}{1-\mathrm{CSR}}\right) \quad (1)$$

where CSR is the capture success ratio across trials within each copper concentration.

Survival curves.—Time to capture of the first prey fish for each trial was used to assess differences in the distribution of survival times (δC) among treatments. Within each treatment, survival time was ranked across trials and each trial was assigned a decreasing proportion of the total survival of the first prey as per Vilhunen (2006). For example, the first prey captured among control trials had a survival time of 6 seconds. Up to 6 s,

[4] http://rsbweb.nih.gov/ij/

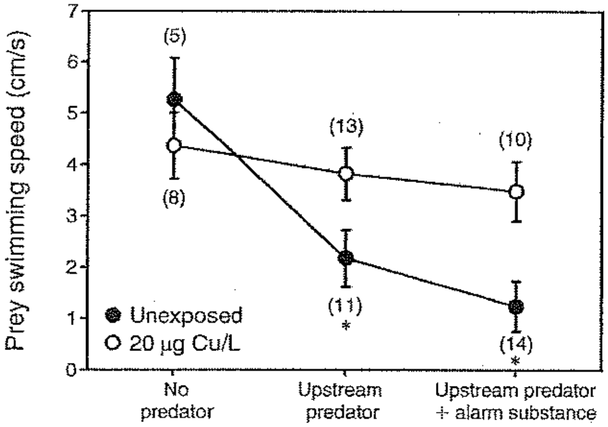

FIG. 1. Activity levels for control (unexposed) and copper-exposed (20 μg Cu/L for 3 h) juvenile coho downstream from one of three levels of predation risk; a compartment with a predator absent, a cutthroat trout predator present, and predator present plus the addition of juvenile coho skin extract. Swimming speed was recorded over 5 min at the end of the 30-min prey acclimation period. Significant differences ($P < 0.05$) from unexposed control are marked with an asterisk. Numbers by each symbol are the sample sizes. Error bars indicate ±SE.

prey survival was 100%. At 6 s, survival across control trials dropped to 15/16, or 93.75%.

For each treatment, the proportion surviving was analyzed as a function of survival time by non-linear regression using the following sigmoid equation:

$$P(T) = \frac{1}{1 + e^{k(T - \mathrm{ST50})}} \qquad (2)$$

where k was the slope of the linear portion of the curve, indicating how quickly survival declined with time, T was time in $\log_{10}$(number of seconds), and ST50 was the midpoint of the curve, the $\log_{10}$ survival time for 50% of trials—analogous to the median survival time. For significantly different distributions, a t test assessed differences in the slope and midpoint among treatments. The benefit of using this method over simply comparing the central tendency of survival time among treatments was that we could compare not only the median survival time, but also the shape of the relationship between survival and time.

To calculate survival probabilities for copper treatments relative to the control treatment, we solved Eq. 2 for survival time, T, using the control slope (k) and midpoint (ST50) from Table 4:

$$T = k^{-1} \times \ln\left(\frac{1}{P} - 1\right) + \mathrm{ST50}. \qquad (3)$$

For given control survival probabilities (0.95 and 0.5), we used Eq. 3 to calculate the associated prey survival time. These times were then used in Eq. 2 with the respective slopes and midpoints for various copper exposures to estimate the related survival probability at that time for coho in each copper exposure.

RESULTS

Copper-exposed coho prey are behaviorally unresponsive to alarm cues.—We found a significant interaction between copper exposure and upstream predator cues with respect to their effect on coho activity ($F_{2,55} = 6.083$, $P = 0.054$; Fig. 1). In the absence of proximal predator cues, i.e., no upstream predator or conspecific skin extract, coho swam at an average speed of 5.2 cm/s (control condition; Fig. 1). A significant alarm response (tendency toward motionlessness) was elicited by the presence of a predator (2.1 cm/s; $F_{1,55} = 4.813$, $P = 0.032$) and a predator together with an upstream introduction of skin extract (1.2 cm/s; $F_{1,55} = 8.738$, $P = 0.005$). When the prey was exposed to copper, upstream predator cues had no effect on activity (combined 3.9 cm/s; $F_{2,55} = 0.518$, $P = 0.599$). Exposure to copper (20 μg/L) alone did not significantly affect baseline swimming activity (predator absent; 4.3 cm/s, $F_{1,55} = 0.734$, $P = 0.395$). Based on previous work (Baldwin et al. 2003), juvenile coho would be expected to recover ~20% of lost olfactory function during the 30 min acclimation interval in clean water used in these behavioral experiments. Nevertheless, copper-exposed fish were still unresponsive to chemical predator cues.

Similar to flow-through trials, control coho in static trials showed a strong alarm response to skin extract, as indicated by a reduction in swimming speed to 1.0 cm/s (Fig. 2). The magnitude of this alarm response decreased with increasing copper exposure. The average swimming speed of coho exposed to copper at 20 μg Cu/L was 4.9 cm/s and comparable to the baseline swimming speed of unexposed control fish in the flow-through trials (5.2 cm/s; Fig. 1). The loss of the alarm response was

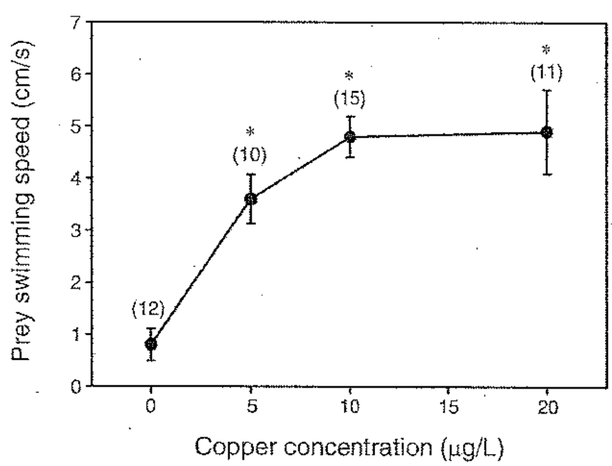

FIG. 2. Alarm behavior in juvenile coho prey at the outset of predation trials. Predators were located within the trial arena behind an opaque divider. Prey swimming speed was recorded at the end of the 15-min prey acclimation, after the presentation of conspecific skin extract. An asterisk indicates that juvenile coho unexposed to copper (0 μg/L) were significantly less active (i.e., were alarmed) relative to copper-exposed coho at all copper exposure concentrations ($P < 0.05$). Error bars indicate ±SE.

TABLE 3. Median values (min, max) for time to first attack (δA), time to first capture (δC), time between δA and δC, number of attacks to δC (A), and frequency of attacks.

[Cu]‡ (μg/L)	δA (s)	δC (s)	δC − δA (s)	A	Attack frequency (s^{-1}) §
May					
0	29.4 (4.2, 218.4)	41.7 (6, 256.8)	3.3 (0, 106.2)	2 (1, 5)	0.75 (0.029, 16.67)¶
5	8.4 (0, 102)*	13.2 (3, 175.8)†	3 (0, 73.8)	3 (1, 7)	1.11 (0.054, 16.67)
10	6 (1.8, 97.2)†	9.3 (3, 422.4)*	2.7 (0, 422.47)	2 (1, 6)	1.25 (0.007, 16.67)
20	4.5 (0.6, 426.6)*	9.6 (1.2, 426.6)*	3 (0, 6)	3 (1, 6)	1.15 (0.667, 16.67)
June					
0	22.2 (4.2, 156)	23.4 (5.4, 159)	1.8 (0, 7.2)	3 (1, 6)	1.67 (0.555, 16.67)
10	3 (0, 114)*	6.9 (0.6, 124.8)*	3 (0, 12)	3 (1, 6)	1.5 (0.222, 16.67)
10#	5.4 (1.2, 27)*	9 (1.2, 34.8)*	2.1 (0, 28.8)	3 (1, 10)	1.57 (0.347, 16.67)

* $P < 0.05$; † $P < 0.1$.
‡ Copper exposures for 3 h prior to predation trial.
§ A/(δC − δA).
¶ To calculate attack frequency for δC − δA = 0, number of attacks was divided by 0.06 s.
# Predators also exposed to copper.

significant among copper-exposed coho relative to controls ($F_{3,44} = 14.27$, $P < 0.001$; Dunnett's post hoc test, $P \leq 0.001$).

Copper-exposed coho are more vulnerable to predation.—Prior copper exposure significantly affected time to first attack (ANOVA, $F_{3,58} = 3.550$, $P = 0.020$) and time to first capture ($F_{3,58} = 4.33$, $P = 0.008$) of juvenile coho by predators (Table 3). Time to attack (δA) and time to capture (δC) were reduced for all copper treatments compared to controls (Dunnett's post hoc test (0 vs. 5, 10, 20 μg/L): $P_{\delta A} = 0.031, 0.069, 0.014$; $P_{\delta C} = 0.062, 0.020, 0.004$). Other predator–prey interactions were unaffected by copper exposure (Table 3), including time between first attack and capture (Kruskall-Wallis $\chi^2_{3,63} = 2.43$, $P = 0.488$), number of attacks ($F_{3,58} = 0.624$, $P = 0.602$), and attack frequency ($\chi^2_{3,63} = 6.00$, $P = 0.111$).

Time to attack and time to capture were positively correlated because time to capture includes time to first attack (δC = δA + [δC − δA]). The correlation between time to attack and time to capture was very strong ($r_S = 0.959$, $n = 63$, $P < 0.001$). When log-transformed to allow calculation of a coefficient of determination, time to attack explained nearly all the variation in time to capture ($r^2 = 0.912$). Capture–attack interval (δC − δA) was not significantly different among treatments ($\chi^2_{3,63} = 2.43$, $P = 0.488$, median = 3 s), and was not correlated with δA ($r_S = 0.094$, $n = 63$, $P = 0.470$), suggesting that the primary component of the predation sequence affected by copper was prey detection leading to attack (δA).

Although the number of attacks to capture (A) was not different among treatments (Table 3), the capture success rate (probability of capturing prey on the first attack) increased with copper concentration (Fig. 3). Capture success rate was significantly correlated with increasing copper exposure concentration ($F_{1,3} = 60.060$, $P = 0.016$, $r^2 = 0.968$) following the equation $\log_e(\text{OR}) = 0.062[\text{Cu}] - 2.039$, where [Cu] is dissolved copper concentration in μg/L. Standard error for the slope was 0.008 and was 0.092 for the intercept.

Exposing predators to copper does not improve the evasion success of prey.—In a separate set of predation trials, we determined the effect of co-exposing predators and prey to copper at 10 μg/L (Table 3). Similar to the first set of predation trials, copper exposure affected time to attack ($F_{2,42} = 8.639$, $P = 0.001$) and time to capture ($F_{2,42} = 6.368$, $P = 0.004$). However, these metrics were not significantly different from experiments in which prey alone were exposed (Tukey's post hoc, δA, $P = 0.340$; δC, $P = 0.715$). Number of attacks ($F_{2,42} = 1.429$, $P = 0.251$), time between first attack and capture ($\chi^2_{2,45} = 0.732$, $P = 0.693$), and attack frequency ($\chi^2_{2,45} = 0.318$, $P = 0.853$) were not affected by copper exposure (prey exposed and predators plus prey exposed were similar to controls). In addition, exposing predators to copper did not change the likelihood of capturing prey on the first attack (25% for exposed prey only vs. 31% for co-exposed predators and prey; $\chi^2_1 = 0.643$, $P = 0.423$).

Copper exposure reduces prey survival.—Survival curves for each treatment were constructed from the

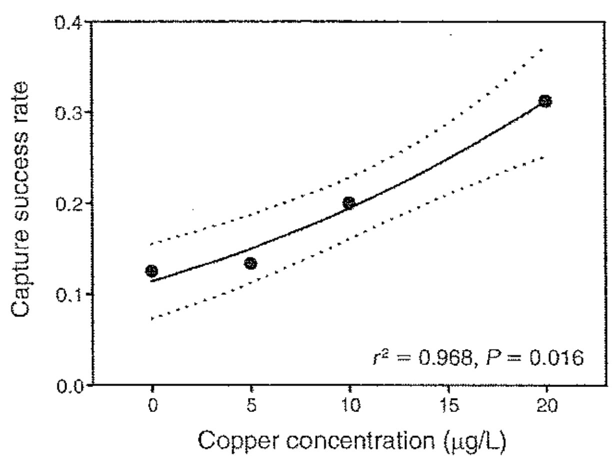

FIG. 3. Proportion of trials for which prey were captured on the first attack (capture success rate). Dashed lines are 95% confidence bands for the logistic regression. Capture success rate is described by the equation $e^F/(1 + e^F)$, where $F = 0.062[\text{Cu}] - 2.039$ (see *Results* for associated statistics).

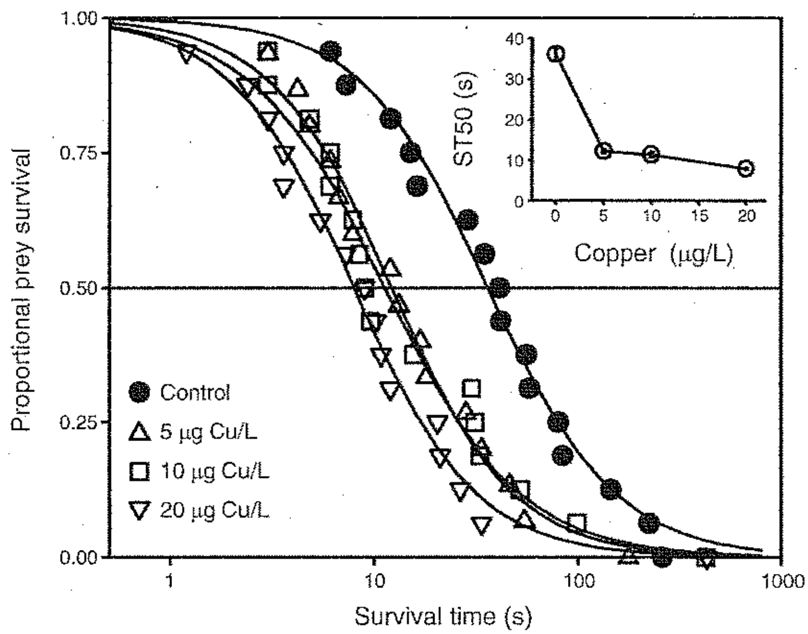

FIG. 4. Survival curves for control and copper-exposed coho in predation trials. Each point represents one predation trial, and survival times are based on the first prey fish consumed. The inset shows the midpoints of each curve, representing median survival time (ST50) for each treatment as a function of copper exposure.

time to first capture among trials (Figs. 4 and 5). Slopes, midpoints, and coefficients of determination for these curves are presented in Table 4.

Survival curves for copper treatments (Fig. 4) were significantly different from the control curve (F test, all $P < 0.001$). This was due to differences in midpoint (t test, all $P < 0.001$), as slope between survival and time for each copper treatment was similar to the slope of the control curve (t test, all $P > 0.480$). Among copper treatments, 5 µg/L and 10 µg/L produced similar survival curves ($F_{2,27} = 2.222$, $P = 0.128$), with similar slopes (t_{27}, $P = 0.314$) and midpoints (t_{27}, $P = 0.274$),

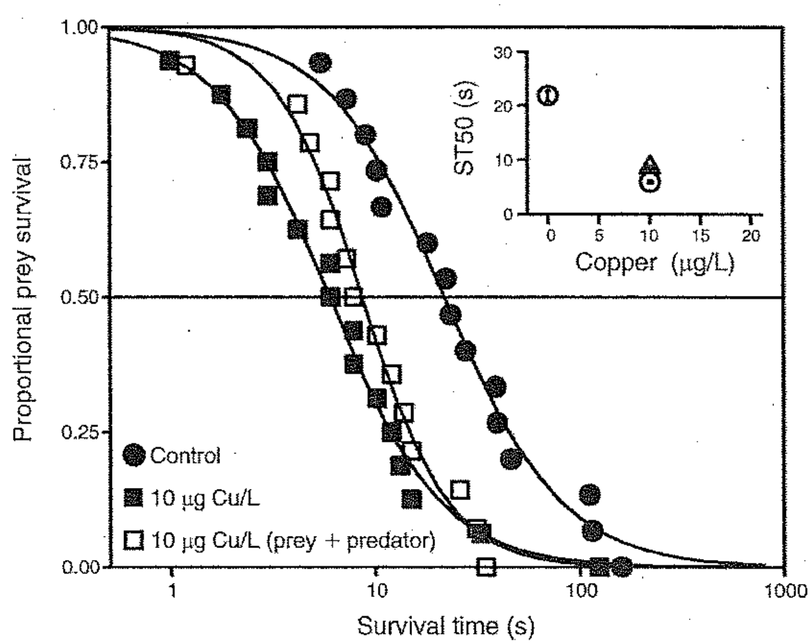

FIG. 5. Survival curves for predation trials in which prey alone or predators and prey were both exposed to copper (10 µg/L). Each point represents one trial, and survival times are based on the first prey fish consumed. Insets show the midpoints of each curve, representing median survival time (ST50) for each treatment as a function of copper exposure. The triangle symbol in the inset represents the ST50 for trials in which both predator and prey were exposed to copper.

TABLE 4. Sigmoid regression parameters for the survival curves.

[Cu] (μg/L)	r^2	ST50†	SE	K‡	SE	N
May						
0	0.984	1.557	0.016	3.219	0.186	16
5	0.988	1.085	0.014	3.36	0.166	15
10	0.965	1.052	0.026	3.042	0.262	16
20	0.987	0.898	0.014	3.333	0.17	16
June						
0	0.983	1.338	0.016	3.493	0.213	15
10	0.985	0.774	0.014	3.659	0.203	16
10§	0.985	0.935	0.012	4.768	0.302	14

Note: All $P < 0.001$.
† Log of time to 50% survival across trials, midpoint of curve, measured in seconds.
‡ Slope of the sigmoid regression curve.
§ Predators and prey both exposed to copper.

whereas these curves had significantly different midpoints (Table 4) than the curve for 20 μg/L (both $P < 0.004$).

For the predation trials in which both predators and prey were exposed (Fig. 4), survival curves for copper treatments (10 μg/L) were again different from the control curve (F test, both $P < 0.001$). Prey alone exposed to 10 μg/L resulted in a survival curve that had a similar slope (t_{27}, $P = 0.577$), but different midpoint (t_{27}, $P < 0.001$) than the control curve. Exposing predators and coho to 10 μg/L affected both the slope (t_{25}, $P = 0.002$) and the midpoint (t_{25}, $P < 0.001$) of the survival curve compared to the control curve. The predator + prey copper curve also had a different slope (t_{26}, $P = 0.005$) and midpoint (t_{26}, $P < 0.001$) compared to the prey-only copper exposures. Therefore, exposing predators to copper resulted in a subtle change in the shape of the survival curve, although it was not strong enough to alter predator–prey metrics (see *Exposing predators to copper does not improve the evasion success of prey*).

We calculated survival probabilities for copper exposures relative to controls using Eqs. 1 and 2. At 4.4 s, 95% of control coho were alive. Relative survival probabilities for copper-exposed coho were 82% for 5 μg/L, 78% for 10 μg/L, and 70% for 20 μg/L. The median survival time for controls was 36.1 s (50% survival; Table 4). Corresponding survival probabilities for copper exposures were 17%, 18%, and 10% for 5 μg/L, 10 μg/L, and 20 μg/L treatments, respectively.

DISCUSSION

We have evaluated the effects of copper exposure on juvenile coho predator avoidance behaviors and the related consequences for coho survival during encounters with predatory wild cutthroat trout. We find that relatively brief (3 h) exposures to copper at 5–20 μg/L eliminated the behavioral alarm response in coho prey, leading in turn to increased detection, reduced evasion, and reduced survival during predation trials.

The magnitude of the coho alarm response was greatest when the presence of an upstream predator was paired with skin extract, consistent with previous studies (e.g., Laûtala and Hirvonen 2008). Our results showing a copper-induced loss of antipredator behavior reinforces and extends previous observations for juvenile coho. Sandahl et al. (2007) found that hatchery-raised coho become motionless (freeze) following presentation of a conspecific skin extract, and that this alarm response is reduced or abolished by copper exposure (3h; 2–20 μg/L). We have extended this behavioral toxicity to wild coho, and shown that copper also renders coho unresponsive to possibly distinct chemical cues emanating from a proximal upstream predator. This is consistent with copper's broad neurotoxicity across non-overlapping olfactory receptor neuron populations in the salmon olfactory epithelium (Baldwin et al. 2003).

Copper-exposed prey were easier for predators to identify, attack, and capture. This was due primarily to higher activity than alarmed controls, leading to a more rapid detection by cutthroat trout. For juvenile salmon, activity critically determines the likelihood of detection by visually guided predators such as larger salmonids, piscivorous birds, and river otters. For example, in predation trials with Mergansers, attacks on active juvenile coho were 15 times more frequent than attacks on inactive coho (Martel and Dill 1995). In the current study, copper also negatively influenced evasion of a predator once an attack was initiated, i.e., it became increasingly likely that prey would be captured on the first attack at higher copper exposure concentrations. Evasion success depends in part on whether the prey fish is aware of proximal danger (Lima and Dill 1990). In the current study the threat awareness of unexposed controls was heightened via the introduction of conspecific skin extract prior to the onset of the trial. By comparison, copper-exposed coho were unresponsive to the chemical alarm cue, thus unaware of the impending threat, and less prepared to evade once an attack sequence was initiated.

Copper toxicity to the coho lateral line mechanosensory system may have contributed to the observed reduction in evasion success. As with olfactory receptor neurons, copper is toxic to lateral line neurons that are directly exposed to contaminated waters (Linbo et al.

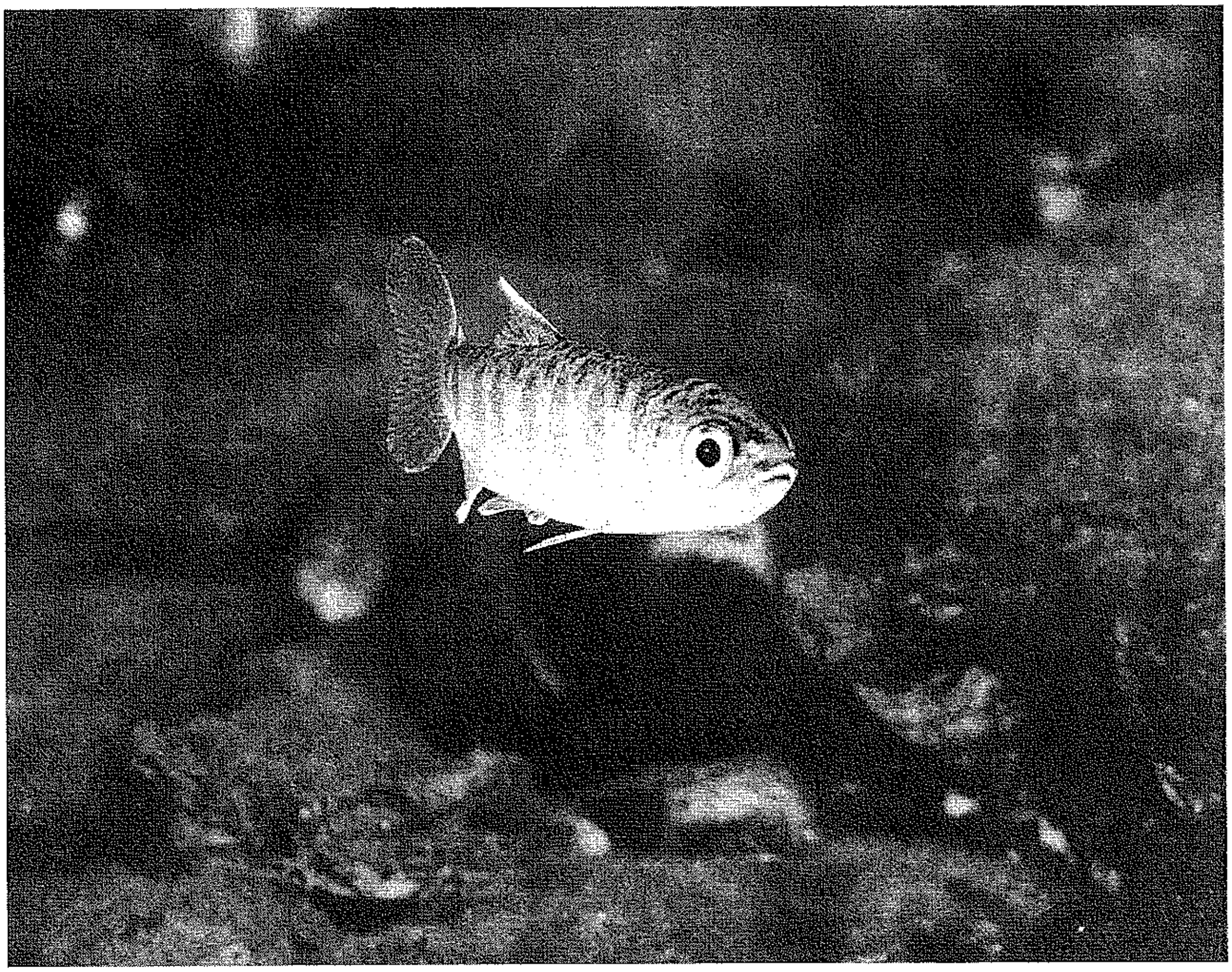

Plate 1. Juvenile coho salmon are sensitive to olfactory alarm cues. Photo credit: Morgan Bond.

2006). The lateral line system in salmon and other fish responds to water displaced by an approaching predator and triggers a well-studied sequence of evasive behaviors (the C-type startle reflex: reviewed by Bleckmann 1993). Conversely, predators can capture prey without a functioning lateral line system. For predatory bass (*Micropterus salmoides*) and muskellunge (*Esox masquinongy*), prey capture success rate was unaffected by cobalt exposures at concentrations toxic to the lateral line (New 2002). Despite similar prey capture success, some aspects of the attack sequence were altered in cobalt-exposed predators relative to controls, including shorter distance to strike (both predators) and mean angular approach (muskellunge). We found a subtle shift in the midpoint and slope of the prey survival curve when predators were co-exposed to copper, possibly due to copper neurotoxic effects on the lateral line of cutthroat trout predators. Additional behavioral studies with a focus on lateral line function are warranted, particularly for predator–prey encounters under low visibility conditions.

Prey may make compensatory behavioral changes to improve their likelihood of surviving an attack (Lima and Dill 1990, Lind and Cresswell 2005); however, we saw no evidence of this among copper-exposed coho. Also, co-exposing predators and prey to copper did not eliminate the reduced survival time of prey relative to exposing prey alone. This indicates that sublethal copper toxicity will have a disproportionate impact on prey in predator–prey dynamics, irrespective of whether the visually guided predators occupy the same contaminated surface waters (e.g., cutthroat trout and other piscivorous fish) or attack from the air above (e.g., Kingfishers and other birds).

The arena used for the predation trials lacked substrate, making it easier for cutthroat trout to detect and successfully capture alarmed coho relative to an encounter under natural conditions. Substrate complexity improves juvenile coho crypsis (Donnelly and Dill 1984) and provides refuge. Turbidity in streams can further constrain visual detection (Mazur and Beauchamp 2003). Thus, our observed differences in predation vulnerability between copper-exposed and unexposed prey would likely be magnified in natural stream habitats where survival rates for alarmed (predator aware) coho are higher.

Our findings likely extend to other fish species. For example, Baldwin et al. (2011) recently showed that the olfactory toxicity of copper is comparable in coho and steelhead, and also comparable among fish raised in hatchery and natural environments. Numerous other studies have demonstrated the olfactory-mediated neurobehavioral toxicity of copper for alarm behavior (reviewed by Tierney et al. 2010) in both controlled laboratory settings (e.g., Beyers and Farmer 2001, Jaensson and Olsen 2010) and in situ in copper-contaminated habitats (McPherson et al. 2004, Mirza et al. 2009). Copper impacts on chemosensory function also extends to other taxa; for example, disruption of the kairomone-mediated morphological predation defense of zooplankton (*Daphnia pulex*) and altered olfactory-based feeding behaviors of leeches (*Nephelopsis obscura*; Pyle and Mirza 2007) have similar toxicity thresholds (~5 μg/L).

The toxic effects of copper have been remarkably consistent in coho salmon across biological scales, from the functional responsiveness of receptor neurons in the olfactory epithelium (Baldwin et al. 2003, Sandahl et al. 2004, 2007, McIntyre et al. 2008, Baldwin et al. 2011) to the olfactory-mediated behavior of individual animals (Sandahl et al. 2007; this study) to coho survival in predator–prey interactions (this study). Across these studies, the thresholds for neurobehavioral toxicity have been in the range of 2–5 μg/L (although this will shift upward in waters with relatively high dissolved organic carbon content: McIntyre et al. 2008). Notably, this is very close to the toxicity threshold reported for rainbow trout olfaction more than 35 years ago (7 μg/L: Hara et al. 1976). Olfactory disruption as measured at the olfactory epithelium is therefore a reliable proxy for behavioral impairment and reduced survival.

In conclusion, our findings are an example of how chemical habitat degradation in the form of water pollution can have nuanced but important impacts on the behavioral ecology of salmon. The effects of copper on coho survival are context-dependent and likely to go unnoticed in conventional field surveys of juvenile salmon abundance, habitat use patterns, and physical habitat quality. New biological indicators of copper toxicity, including diagnostic changes in gene expression within the salmon olfactory epithelium (e.g., Tilton et al. 2008), may eventually reveal the extent of sensory isolation in wild salmon under natural exposure regimes. In the interim, copper control strategies will likely improve juvenile salmon survival and minimize the disruption of a range of chemosensory-dependent behaviors. This includes, for example, legislation recently enacted in Washington State (SB6557) and California (SB346) to phase out the use of copper and other metals in motor vehicle brake pads.

Acknowledgments

The authors thank J. Martin Grassley, Chris Tatara, Barry Berejikian, Dave Rose, Matt Gilman, Sarah McCarthy, and Evan Malczyk for technical assistance during this project. Coho during 2008 were donated by E. McClelland and K. Naish (University of Washington School of Aquatic and Fishery Sciences, Seattle, Washington, USA). This research was supported by the NOAA Coastal Storms Program and a grant to Jenifer McIntyre from the U.S. Environmental Protection Agency's Science to Achieve Results (STAR) program. Although the research described in the article has been funded in part by the U.S. Environmental Protection Agency's STAR program (grant FP91656301), it has not been subjected to any EPA review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

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Landscape Ecotoxicology of Coho Salmon Spawner Mortality in Urban Streams

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Abstract

In the Pacific Northwest of the United States, adult coho salmon (*Oncorhynchus kisutch*) returning from the ocean to spawn in urban basins of the Puget Sound region have been prematurely dying at high rates (up to 90% of the total runs) for more than a decade. The current weight of evidence indicates that coho deaths are caused by toxic chemical contaminants in land-based runoff to urban streams during the fall spawning season. Non-point source pollution in urban landscapes typically originates from discrete urban and residential land use activities. In the present study we conducted a series of spatial analyses to identify correlations between land use and land cover (roadways, impervious surfaces, forests, etc.) and the magnitude of coho mortality in six streams with different drainage basin characteristics. We found that spawner mortality was most closely and positively correlated with the relative proportion of local roads, impervious surfaces, and commercial property within a basin. These and other correlated variables were used to identify unmonitored basins in the greater Seattle metropolitan area where recurrent coho spawner die-offs may be likely. This predictive map indicates a substantial geographic area of vulnerability for the Puget Sound coho population segment, a species of concern under the U.S. Endangered Species Act. Our spatial risk representation has numerous applications for urban growth management, coho conservation, and basin restoration (e.g., avoiding the unintentional creation of ecological traps). Moreover, the approach and tools are transferable to areas supporting coho throughout western North America.

Citation: Feist BE, Buhle ER, Arnold P, Davis JW, Scholz NL (2011) Landscape Ecotoxicology of Coho Salmon Spawner Mortality in Urban Streams. PLoS ONE 6(8): e23424. doi:10.1371/journal.pone.0023424

Editor: Howard Browman, Institute of Marine Research, Norway

Received January 31, 2011; **Accepted** July 17, 2011; **Published** August 17, 2011

Funding: This work was supported by the National Oceanic and Atmospheric Administration - Coastal Storms Program; U.S. Fish and Wildlife Service - National Contaminants Program; City of Seattle (Seattle Public Utilities); and the U.S. Environmental Protection Agency - Region 10. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

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Introduction

In recent decades, human population growth and development have continued to increase along the coastal margins of North America [1]. The associated changes in land cover and human land use have elevated land-based sources of pollution, and toxic stormwater runoff in particular, to become one of the most important threats to the biological integrity of basins, lakes, estuaries, and nearshore marine environments [2]. In the United States, concerns related to non-point source pollution have gained momentum over the past decade (e.g., [3,4]). This has culminated most recently in the designation of "water quality and sustainable practices on land" as one of nine National Priority Objectives for the newly established National Ocean Council, together with ecosystem-based management, marine spatial planning, climate change and ocean acidification, and changing conditions in the Arctic [2]. For toxic runoff, however, the connections between unsustainable practices on land and the decline of ecological resilience in aquatic habits remain poorly understood.

In western North America, semelparous anadromous salmonids (*Oncorhynchus* spp.) typically migrate thousands of kilometers in their lifetimes. They hatch and rear in freshwater, migrate seaward to capitalize on the productivity of the oceans to grow rapidly and reach sexual maturity, and then return to their natal streams to spawn and die. Certain salmonids, including pink (*O. gorbuscha*) and chum (*O. keta*) migrate to the ocean relatively soon after hatching. Others, however, such as Chinook (*O. tshawytscha*), steelhead, (*O. mykiss*), sockeye (*O. nerka*), and coho (*O. kisutch*) may spend one or more years in freshwater lakes, rivers and streams. Because of this extended freshwater residency, juveniles of these species are potentially more vulnerable to anthropogenic modifications of freshwater habitat quality [5].

In contrast to the high mortality experienced by juvenile salmonids, mortality at the adult spawner life stage is relatively low. Familiar natural causes of mortality include predation, disease [6,7,8,9], stranding (following high flows), elevated stream temperatures, and competition – e.g., in habitats with abundant salmon returns and limited spawning substrate. Various human activities such as recreational and commercial fishing, stream dewatering, and the placement of migration barriers can also increase salmon spawner mortality. In general, however, salmon spawner mortality has not been attributed to toxic chemical contaminants in stormwater runoff – a data gap that may be due, in part, to 1) the relative rarity of salmon spawners in urban basins with poor water quality, and 2) the logistical difficulty of implementing toxicity studies on migratory, seawater-to-freshwater transitional adults.

The exception is a recently documented phenomenon of returning adult coho salmon dying at high rates in urban and urbanizing streams in lowland Puget Sound region, which includes the greater Seattle metropolitan area [10]. Coho return to small coastal stream networks to spawn each fall. Entry into freshwater is triggered by early autumn rainfall and rising stream flows. Since there had been extensive habitat degradation and loss in these lowlands, many basins were targeted for stream restoration projects in the 1990s. Subsequent surveys to evaluate project effectiveness discovered that many coho salmon were dying in newly-accessible stream reaches before they were able to spawn – i.e., female carcasses were found in good condition (ocean bright colors) with skeins (membrane or sac that contains the eggs within the fish) filled with unspawned eggs [10]. In addition, affected coho from several different urban basins showed a similar progression of symptoms leading up to death, including disorientation, lethargy, loss of equilibrium, mouth gaping, and fin splaying. Systematic daily spawner surveys in recent years (2002–2009) have shown that adult mortality rates in urban streams are consistently high (relative to spawning coho salmon in more pristine areas), ranging from ~25–90% of the total fall runs [10]. Mortality rates of this magnitude likely have important negative consequences for maintaining viable coho populations [11]. Consistent with this, most coho mortalities observed over the past decade were spawners that strayed (did not home to their natal stream reaches) into these restored urban freshwater habitats.

The precise underlying cause of recurrent coho die-offs remains under investigation. An initial weight-of-evidence forensic study has systematically ruled out stream temperature, dissolved oxygen, poor overall spawner condition, tissue pathology (e.g., gill), pathogen prevalence or disease, and other factors commonly associated with fish kills in freshwater habitats (Scholz et al., unpublished data). These findings, together with the rapid onset of the syndrome, the nature of the symptoms (e.g., gaping and disequilibrium), and the consistent re-occurrence within and between urban basins over many years together point to toxic stormwater runoff from urban landscapes as the likely cause of coho spawner mortality. Urban runoff and stormwater-influenced combined sewer overflows (CSOs) contain an exceptionally complex mixture of chemical contaminants. Specifically, urban streams are receiving waters for runoff and discharges containing pesticides [12], metals [13], petroleum hydrocarbons [14], plasticizers, flame-retardants, pharmaceuticals, and many other potentially toxic chemicals. The list of possible causal agents is therefore long.

The above chemical complexity notwithstanding, there are several reasons to suspect motor vehicles as sources of toxics that are killing returning coho. Vehicles deposit many compounds on road surfaces via exhaust emissions, leaking fluids, and the wearing of tires, brake pads and other friction materials [15]. Emissions contain nitrogen and sulfur dioxide, benzene, formaldehyde, and a large number of polycyclic aromatic hydrocarbons (PAHs). Fluids, including antifreeze and motor oil, contain ethylene and propylene glycol and PAHs. Tire wear releases zinc, lead, and PAHs onto road surfaces [16], and brake pad wear is a major source of copper, zinc, nickel, and chromium [16,17]. Collectively, these contaminants accumulate on streets and other impervious surfaces until they are mobilized by rainfall and transported to aquatic habitats via runoff. Polycyclic aromatic hydrocarbons and metals such as copper are known to be toxic to fish, although acute lethality usually occurs at exposure concentrations that are higher (by orders of magnitude) than those typically detected in urban streams. It is likely that fall stormwater pulses contain higher concentrations than winter and spring due to the potential buildup of contaminants during the relatively dry summer months.

Although the adult die-off phenomenon has been observed in all Seattle-area urban streams where coho salmon occur, the overall rate of mortality has varied among basins. In qualitative terms, a higher proportion of returning animals have survived to spawn in basins that have more open space (e.g., parks and woodlands). Conversely, mortality rates have been consistently higher in basins with proportionately greater "urban" land cover and land uses. This raises the possibility of a quantitative relationship between discrete basin characteristics and coho survival and spawning success. Such a relationship would be important for several reasons. First, if coho mortality is significantly correlated with one or more land cover or land use variables, the latter could be used to identify unmonitored lowland basins where coho populations are at greatest risk. Second, it could provide a means to evaluate how future human population growth and development might impact wild coho populations in Puget Sound (and elsewhere) that are currently healthy. Finally, it could narrow the list of potentially causative pollution sources in urban basins, thereby focusing future toxicological studies to identify the specific contaminants involved.

In this study we performed a spatial analysis to identify landscape variables that correlate most closely with surveyed rates of coho spawner mortality across six different basins in Puget Sound. The variables included land use and land cover, tax parcel types, roadways, and impervious surfaces. We then used the information from these correlations to generate spatially explicit predictions of recurrent spawner losses in unmonitored basins throughout the four most densely populated counties in the greater Seattle metropolitan area.

Materials and Methods

Study Sites

We characterized habitat conditions within the drainage basins from streams at six sites in the Puget Sound lowlands (Figure 1). We chose these sites because coho spawner mortality has been monitored at these locations for several years (2000–2009; [10]). The sites represent a wide range of anthropogenic alteration, from highly urbanized (e.g., Longfellow Creek) to relatively undisturbed (e.g., Fortson Creek). Fortson Creek is considered a non-urban site, whereas the other five sites are urban streams and have varying degrees of development. The urban streams have all been a focus of varying restoration project efforts aimed at enhancing habitat quality for anadromous Pacific salmon. With the exception of the relatively unaltered Fortson Creek site, all site basins had impervious surface proportions well above the levels (5–10%) commonly associated with the decline of biological integrity in streams [18,19].

Confirmed observation of the coho spawner mortality syndrome (see below) within a stream system was a key factor in study site selection. Importantly, natural production of coho in Seattle-area urban streams is very low. Not unexpectedly, recent modeling has shown that local coho population abundance declines precipitously at rates of spawner mortality documented for these drainages [11]. The adult returns to these streams are thus likely to be animals straying into sink or attractive nuisance habitats. Conversely, the syndrome has not been documented in streams where coho are relatively abundant – i.e., non-urban basins, as confirmed by a full season of daily stream surveys on Fortson Creek. Therefore, to evaluate the phenomenon in relation to land cover, we were constrained to streams where coho are affected, even if adult returns to these basins were low in certain years. Lastly, there is no evidence that the mortality syndrome is related to the origin of the spawners (i.e., hatchery vs. wild fish). For example, artificially propagated coho that return as adults to regional hatchery facilities in non-urban basins are unaffected.

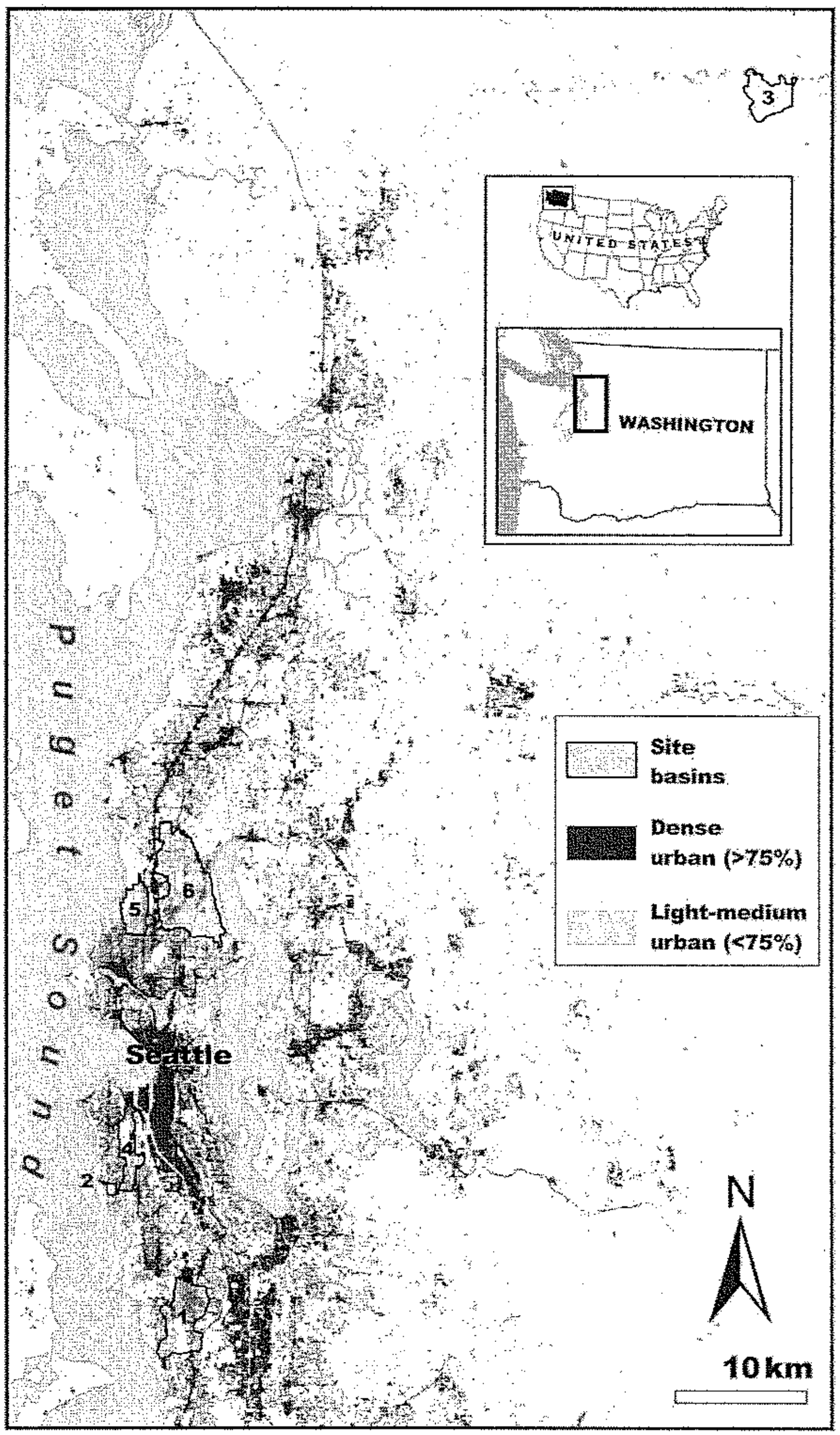

Figure 1. Six study sites where coho spawner mortality was monitored and landscape conditions were quantified. Main map depicts the Greater Seattle Metropolitan Area in Washington State, which is within the Puget Sound/Georgia Basin of the Pacific Northwest, United States of America (USA). Inset map illustrates location of the study sites within Washington State and the location of Washington State within the USA. For reference, red shading on main map represents the relative intensity of urbanization (light-medium and dense urban [23,24]). Drainage basins depicted in yellow shaded polygons represent the total basin flowing into a given stream reach site. Key for site numbers: 1 = Des Moines; 2 = Fauntleroy; 3 = Fortson; 4 = Longfellow; 5 = Piper's; and, 6 = Thornton Creek.
doi:10.1371/journal.pone.0023424.g001

Study Subjects

Coho salmon in this study were all within the Puget Sound/Strait of Georgia Evolutionarily Significant Unit (ESU). An ESU is defined as a group of populations that 1) are substantially reproductively isolated from conspecific populations and 2) collectively represent an important component in the evolutionary legacy of the species [20]. Currently, Puget Sound/Strait of Georgia coho are designated a "species of concern" under the U.S. Endangered Species Act [21].

Coho typically spawn in small (lower order) streams in the Puget Sound lowlands in late fall and early winter and their fry emerge from stream substrates from March to May. Fry reside in riverine habitats for 14–18 months, smolt, migrate to marine environments where they grow rapidly and mature (16–20 months), and finally migrate to their natal basins where they spawn and die [22]. The adult spawners from the six study basins were both marked (adipose fin clipped) and unmarked, suggesting a mix of hatchery and wild origins.

Coho Spawner Mortality

We used existing monitoring data collected as part of daily and weekly spawner surveys in each of the six study locations (Table 1). Data were collected during the fall spawning season from 2000–2009 by Seattle Public Utilities (SPU), the Wild Fish Conservancy, and the Northwest Fisheries Science Center (NWFSC). Streams were checked every few days in the early fall (usually the first or second week in October, depending on rainfall) until the first adult coho was observed. The streams were then surveyed daily for the duration of the fall run, until the last carcass was documented, typically in the first or second week of December. For several years, biologists working for the City of Seattle (Wild Fish Conservancy) also surveyed many of the same urban streams for coho spawner mortality on a weekly basis. Side-by-side comparisons of daily and weekly survey data (e.g., for Longfellow Creek in 2005 and 2007) revealed practically no loss of carcasses to scavengers. Accordingly, we included the weekly survey data in our analyses.

The entirety of the available spawning habitat within a given urban drainage was surveyed for premature adult coho mortality. For some streams, including Longfellow Creek, mid-stream barriers to upstream migration confined adults to the lower portions of the drainage. This made it possible, in the course of a few hours as part of a daily survey, to inspect all sections of the stream that 1) had a gravel substrate suitable for redds (spawning "nests" built by females), and 2) were focal areas for repeated (year-to-year) redd building during successive spawner runs.

Monitoring data were not collected at all sites for all years (Table 1). Mortality among returning coho was quantified only for females on the basis of egg retention – i.e., the number of partially spawned or unspawned female carcasses observed in streams over an entire spawning season. Notably, the total number of returning adults was low for some years and some basins (Table 1). Nevertheless, the aggregate spawner survey data used in this analysis are the most comprehensive currently available.

Geospatial Datalayers

We used existing geospatial datalayers as our source of potential predictor variables and as a proxy for habitat type and condition. The datalayers were generated by a variety of organizations for planning and analytical purposes, making them suitable for running spatial analyses on habitat. They were also available over the entire spatial domain of our predictive model. We used four geospatial datalayers: Land-cover of the Greater Puget Sound Region [23,24]; impervious and impacted surfaces [25]; property type (compiled from King [26], Kitsap [27], Pierce [28] and Snohomish county [29] tax parcel databases), and roadways (Puget Sound Regional Council; PSRC [30]).

The Land-cover of Puget Sound datalayer is the highest quality and most accurate depiction of land use and land cover in the Puget Sound lowlands. The datalayer used 30 m gridded LANDSAT TM imagery from 2002, which was extensively analyzed and corrected to produce an accurate (83% overall accuracy, [24]) depiction of land use and land cover conditions. To reduce the total number of potential predictor variables, we only used the dense urban (>75%); light to medium urban (<75%); and grass, crops and/or shrubs categories. We also combined the mixed and deciduous forest with the coniferous forest category and named it forests.

The impervious and impacted surfaces datalayer was derived from a 2001 LANDSAT TM image with 30 m pixels and an accuracy of 83–91% [25]. This datalayer depicts high to completely impermeable surfaces such as building roofs; concrete or asphalt roads and parking lots; concrete, asphalt or brick sidewalks, pedestrian walkways, and malls; etc.

One of the limitations of these two datalayers was that the pixel size of the source LANDSAT TM imagery is 30 m, so smaller

Table 1. Coho spawner mortality proportion and cumulative number of female carcasses enumerated (in parentheses) by site (columns) and year (rows).

	Des Moines	Fauntleroy	Fortson[1]	Longfellow	Piper's	Thornton
2000	-	0.25 (12)	-	0.74 (135)	0.18 (17)	0.88 (33)
2001	-	0.22 (9)	-	0.61 (111)	0.70 (37)	0.82 (11)
2002	-	0.00 (1)	0.01 (114)[a]	0.86 (57)[a]	0.60 (10)	080 (5)
2003	-	(0)	-	0.67 (18)[a]	0.00 (1)	1.00 (2)
2004	0.63 (30)[a]	(0)	-	0.89 (9)[a]	0.33 (3)	1.00 (1)
2005	-	0.75 (4)	-	0.72 (75)[a]	0.75 (4)	0.50 (8)
2006	-	(0)	-	1.00 (4)[a]	1.00 (9)[a]	1.00 (4)
2007	-	0.75 (4)	-	0.73 (41)[a]	0.20 (5)	0.80 (5)
2008	-	-	-	0.67 (12)[a]	-	1.00 (2)
2009	-	-	-	0.78 (36)[a]	-	-
Overall	0.63 (30)	0.37 (30)	0.01 (114)	0.72 (498)	0.57 (86)	0.83 (71)

A dash (-) indicates survey was not conducted for that year/site.
[a]Northwest Fisheries Science Center (NWFSC) daily surveys, all others were weekly and collected by Seattle Public Utilities (SPU) or the Wild Fish Conservancy [51,52].
[1]Non-urban site.
doi:10.1371/journal.pone.0023424.t001

features, such as roads and precise land cover boundaries, were not adequately captured. In order to address this deficiency, we analyzed property types and roadways, as they are represented as precise polyline and polygon delineations of the corresponding land cover variables. The boundaries in these geospatial datalayers were derived from precise survey data from major metropolitan areas, collected over many years by King, Kitsap, Pierce and Snohomish Counties.

The property types (parcels) datalayer was based on ground surveyed delineations of property, which are used for taxation purposes, with positional accuracy of +/−12 m or less [26,27,28,29]. The original number of parcel types described by each county was between 103 and 292. Using the descriptions in the documentation that accompanied the datalayers, we were able to place each of the original parcel types into one of the five following categories: apartments and condominiums; commercial; industrial; parks and open space; and, residential.

The roadways datalayer was based on ground surveyed road and street centerlines. Each segment had a corresponding functional classification (FC##) code and width, as defined by the Federal Highway Administration [31] Highway Performance Monitoring System, and the Puget Sound Regional Council [30], respectively. We reduced the original nine functional classification types down to two categories: 1) heavily used roads (rural minor collector [FC08]; urban principal arterial - interstate [FC11]; urban principal arterial - other freeways and expressways [FC12]; urban principal arterial - other [FC14]; urban or rural minor arterial [FC16 or FC06]; urban collector [FC17]); and, 2) urban or rural local access roads (FC09 or FC19). We then calculated the total area (total length of given street centerline segment multiplied by its width) of each street functional classification for each corresponding site basin.

Spatial Analyses

We defined the area of influence of the surrounding landscape for each site as the total area draining into that site (basin). Drainage basins for each site were generated using the 'flowaccumulation' command in Environmental Systems Research Institute (ESRI) ArcGIS (v. 9.3). We used a United States Geological Survey (USGS) 10 m digital elevation model (DEM) as the underlying terrain for generating basins. We then intersected the corresponding basin boundary for each of the six sites with each of the geospatial datalayers and their associated categories using ArcGIS. We quantified each geospatial datalayer and its associated category in a given basin as the fraction or proportion of the total area of the basin occupied by that geospatial datalayer or category. Longfellow Creek stood apart from the other sites in terms of the accuracy of the flow accumulation model because an unknown fraction of stormwater runoff in this drainage is diverted into the municipal sewer system. Therefore, the theoretical basin area, based on the terrain represented in the DEM, was not as representative of the true basin area compared with the other five sites.

Statistical Analyses

We used generalized linear mixed-effects models (GLMMs; [32,33]) to test the relationships between geospatial variables and coho spawner mortality. The response was binomial (observed number of female spawner mortalities each year, given the total number of female coho that returned to each site) and the models used a logit link function. All models included a random effect of site on the intercept, which accounts for nonindependence of the repeated samples taken at each site. We constructed a set of 139 candidate models by considering all combinations of the 12 predictors taken one, two, three or four at a time, with the restriction that a model could include at most one predictor from each of the four geospatial datalayers (land cover, impervious surfaces, property types, and roadways). We also excluded combinations of predictors that had a pairwise Spearman rank correlation exceeding 0.9 in absolute value. The candidate set included an intercept-only model as a no-effect baseline against which we could assess the predictive power of the geospatial variables.

We fitted the models using the Laplace approximation to the marginal likelihood [32] in the lme4 package in R [34,35]. We then used Akaike's information criterion, corrected for sample size (AIC_c) to rank the strength of evidence for each candidate model based on the data. Akaike's information criterion is a weight-of-evidence measure that reflects the balance between a model's goodness-of-fit to the data and its parsimony (i.e., number of parameters). Lower AIC_c values indicate greater support, and are reported as differences (ΔAIC_c) relative to the best (smallest) value in the candidate set. We computed Akaike weights [36], which represent the relative support for each model, normalized so the weights sum to unity across the candidate set. We used these weights to compute model-averaged estimates and unconditional standard errors (SEs) for the fixed regression coefficients, and we quantified the relative importance of each predictor using variable weights (i.e., the summed Akaike weights of all models that included that predictor; [36]). These model averaging calculations were based on the 95% confidence set of models (i.e., the top-ranked models whose cumulative Akaike weight is 0.95), after re-normalizing the weights.

Mapping coho spawner mortality

Using the fitted models, we built a map of predicted coho spawner mortality throughout the four counties (King, Kitsap, Pierce and Snohomish) representing much of the Puget Sound lowlands, by applying the GLMM equations to geospatial data from unmonitored basins. We used basins delineated in the National Hydrography Dataset Plus [37] as the underlying mapping unit (300 ha mean, 466 ha SD) and intersected the NHDPlus datalayer with each of the geospatial datalayers used in the statistical analyses. Within the four-county region, we only made spawner mortality predictions in basins where coho salmon presence has been documented, based on current geospatial datalayers generated by the Washington Department of Fish and Wildlife [38]. We then calculated the proportion of each basin that was covered by the selected landscape feature. We generated predicted values of the proportion of mortalities from each model in the 95% confidence set and then model-averaged these values using the normalized Akaike weights [36]. These predictions apply to the average basin in the Puget Sound coho ESU with some given set of habitat conditions, in the sense that the random effect of site was set to zero. To be conservative in representing the precision of the predicted values, we divided the calculated rates of likely coho spawner mortality into three bins: <10%, 10–50%, and >50%. These break points were chosen somewhat arbitrarily to represent low, medium and high spawner mortality rates.

Results

We found strong associations between land use and land cover attributes and rates of coho spawner mortality. Across the 95% confidence set of fitted models, three variables were particularly important for predicting mortality based on high variable weights: impervious surfaces, local roads, and commercial property type (Table 2 and Figure 2). There was substantial model selection

Table 2. AIC weights, model averaged parameter estimates and unconditional confidence intervals for each variable, ranked by AIC_c weight.

Datalayer	Variable	AIC_c weight	Model Averaged coefficient	Unconditional SE
Impervious	Impervious surfaces	0.7158	16.8425	14.5376
Roadways	Local roads	0.5647	−15.6199	68.3331
Property type	Commercial	0.5107	7.9375	8.2616
Land cover	Dense urban	0.3865	−7.7776	16.1614
Property type	Apartments & condominiums	0.2409	−9.5330	31.1917
Roadways	Heavily used roads	0.2019	5.3445	31.5073
Land cover	Forest	0.1163	−0.7793	6.2249
Land cover	Light to medium urban	0.1149	0.3250	2.9751
Land cover	Grass, shrubs & crops	0.0993	0.1664	5.4517
Property type	Residential	0.0975	0.0738	16.8920
Property type	Industrial	0.0547	−0.2475	4.7008
Property type	Parks & open space	0.0000	0.0000	0.0000

doi:10.1371/journal.pone.0023424.t002

uncertainty, reflected in a large 95% confidence set and large number of models with $\Delta AIC_c<2.0$ (37 and 8 of 139 candidate models, respectively; Table 3). In addition, although we excluded highly multicollinear combinations of variables ($|r|>0.9$), many variables were still strongly correlated, resulting in unstable parameter estimates and large unconditional SE estimates (Table 2). Nonetheless, predictive models that included land use and land cover attributes as predictors were clearly superior to the intercept-only model ($\Delta AIC_c = 20.4$; Table 3), supporting the association of these variables with coho mortality.

While the multicollinearity among potential predictors made causal interpretation of the models difficult, it did not preclude predictions of where coho salmon are likely to be affected along an urbanization gradient. Not surprisingly, the highest predicted mortality rates were clustered around the major metropolitan areas of eastern Puget Sound, contained within Snohomish, King, Kitsap, and Pierce counties (Figure 3). In addition, there is a significantly sized area in Eastern Puget Sound that has considerable proportions of the variables (local roads, impervious surface and commercial parcels) most correlated with substantial mortality rates. It is important to note that these predicted values have substantial associated uncertainty and should therefore be interpreted cautiously; however, it is reasonable to use them for assigning the break points for the low, medium, and high mortality rate categories represented on the map.

Discussion

Overall, we have used conventional tools in landscape ecology to shed light on an unusually complex ecotoxicological challenge. Our analyses strongly suggest that specific characteristics of basins in the Puget Sound lowlands are linked to the die-offs of coho spawners that have been widely observed in recent years. Across basins, the strength of the association is greatest for impervious surfaces, local roads, and commercial property. We did not evaluate hydrologic or geomorphic basin characteristics as part of our analysis. Nevertheless, our findings support the hypothesis that coho are being killed by as-yet unidentified toxic chemical contaminants that originate from these types of surfaces and are transported to salmon spawning habitats via stormwater runoff.

Our results extend a large body of scientific information linking urbanization (broadly defined) and degraded water quality to a loss of biological integrity (sensu Karr [39]) and productivity in freshwater stream networks [18,40,41]. Previous studies have generally related land use and land cover variables to macroinvertebrate assemblages in streams [42], or to the relative abundance of salmon and other fish (e.g., [22,43,44]). The present analysis is novel because it relates basin characteristics directly to salmon health and survival, versus species presence or absence. Moreover, it offers new insights on the water quality aspects of urban runoff. The focus of most salmon restoration projects is physical characteristics of spawning and rearing habitat [45]. Most salmon specific restoration projects are deemed successful if they simply restore the physical habitat to a suitable state for a given species [46]. Our study suggests that suitable spawning and rearing habitat may not be supportive of coho salmon persistence when the surrounding landscape is urbanized. The linkages between increased impervious coverage within a basin, increased stormwater runoff, altered hydrologic processes, and ecological decline are well established (e.g., [18]). However, stormwater impacts encompass both physical and chemical drivers of decline, and it can be difficult to distinguish between these via *in situ* assessments because stream invertebrate communities integrate both stressor categories. Coho salmon spawners, by contrast, appear to be promising and specific sentinels for the degraded water quality aspect of urban runoff. Compared to macroinvertebrate sampling and taxa identification, the coho mortality syndrome is relatively easy and inexpensive for non-specialists to monitor in the form of digital video recordings of symptomatic fish, or the presence of unspawned female carcasses in streams.

Interestingly, the mortality syndrome appears to be specific to coho salmon. For example, there were temporally overlapping runs of coho and chum salmon (*O. keta*) in Piper's Creek in the fall of 2006. Whereas all of the adult coho succumbed to the mortality syndrome, the chum were unaffected, with nearly all surviving to spawn (130 of 135 spawned out female carcasses; Scholz et al., unpublished data). Consistent with this, the survey

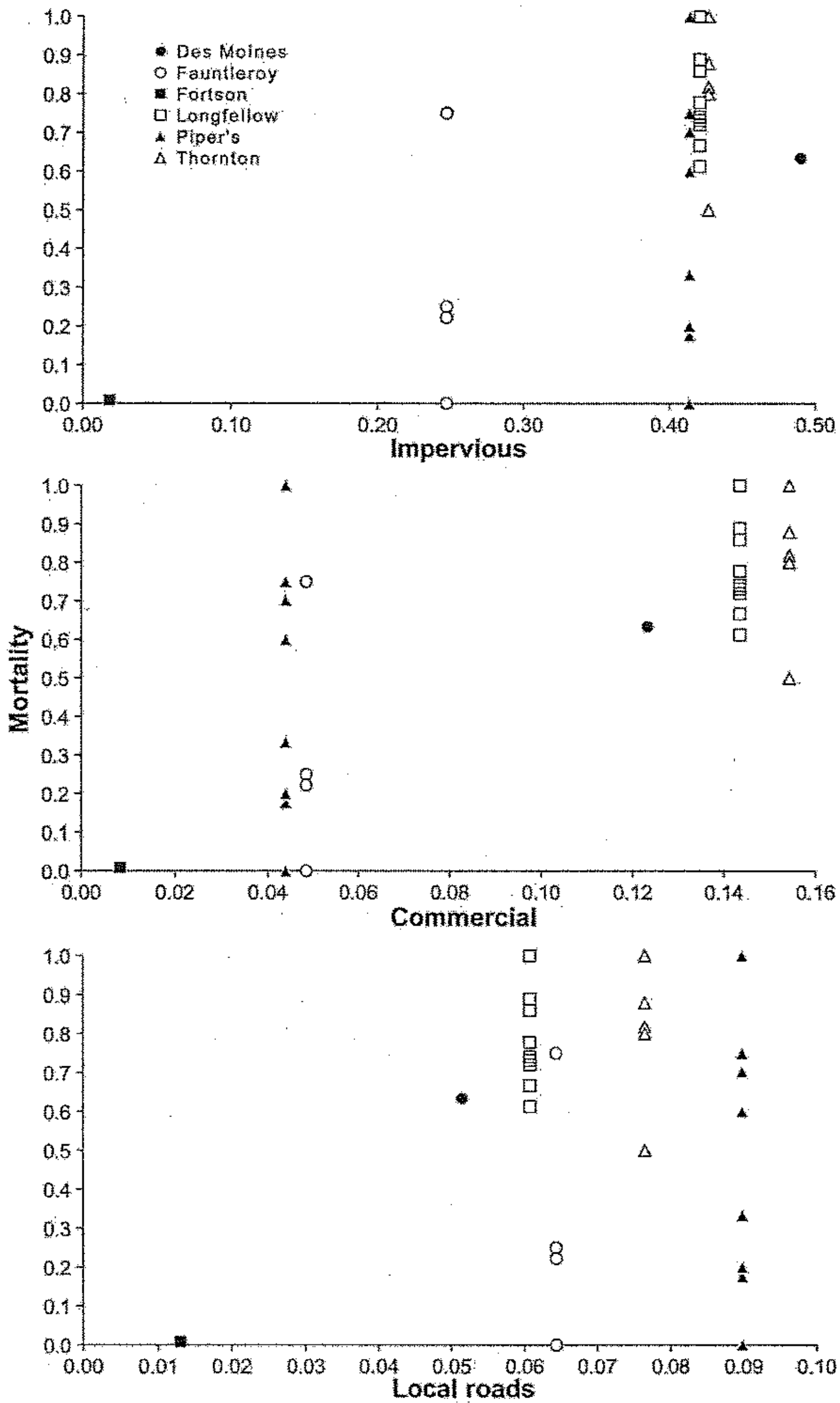

Figure 2. Female coho spawner mortality as a function of the proportion of each of the top three predictors in a given site basin, at the six study sites. Individual points correspond to specific years for each site. Mortality expressed as proportion of all returning females that died in a given year. Solid circle = Des Moines; hollow circle = Fauntleroy; solid square = Fortson; hollow square = Longfellow; solid triangle = Piper's; hollow triangle = Thornton Creek.
doi:10.1371/journal.pone.0023424.g002

teams have not observed the characteristic symptoms (e.g., surface swimming, gaping) among other fish species that inhabit urban streams such as sticklebacks and cutthroat trout. Not only are coho unusual in this respect, the phenomenon appears to be restricted to the adult life stage. In the fall of 2003, surface flows from Longfellow Creek were diverted through streamside sheds housing aquaria that contained individual juvenile coho from the NWFSC hatchery. The juveniles (n = 20) were maintained and observed daily throughout the fall spawner run. Overall juvenile survival was 100%, and the juveniles behaved normally, even on days when symptomatic adults were observed in the nearby stream (Scholz et al., unpublished data). The underlying reasons

Table 3. Summary of the 95% confidence set (37 of a total of 139 candidate models) of candidate models used to generate map of mortality rates, showing intercepts, estimated coefficients, ΔAIC_c and w_{AICc}. Intercept only model included at bottom for reference.

Model	Equation	ΔAIC_c	w_{AICc}
a+b	−4.5664+19.76(a)+44.41(b)	0.000	0.0933
c+d+b	−3.9215−109.56(b)+48.75(c)−29.98(d)	0.046	0.0912
c+e+f	−3.9355+12.94(c)−40.15(e)+38.61(f)	0.372	0.0775
c+d+a	−4.4921+12.61(a)+14.03(c)−7.54(d)	0.579	0.0698
c+g+a	−4.4858+14.31(a)+5.23(c)+3.62(g)	0.669	0.0668
h+a+b	−2.6065+15.89(a)+30.87(b)−2.38(h)	1.150	0.0525
c+a+b	−4.6629+16.37(a)+35.26(b)+2.70(c)	1.357	0.0473
d+a+b	−4.7001+17.52(a)+43.83(b)+1.62(d)	1.576	0.0424
c+e	−4.5943+19.70(c)−53.28(e)	2.425	0.0277
c+d+i+b	−3.0628−83.44(b)+56.38(c)−40.28(d)−7.82(i)	2.485	0.0269
c+j+i+b	−7.3055−130.72(b)+21.23(c)+19.12(i)+10.65(j)	2.543	0.0262
c+d+k+b	−3.9266−94.52(b)+43.32(c)−25.00(d)−1.60(k)	2.613	0.0253
j+a+b	−4.5174+20.03(a)+43.79(b)−0.52(j)	2.752	0.0236
c+d+a+b	−4.0864+3.99(a)−76.44(b)+38.23(c)−23.27(d)	2.885	0.0221
c+d+a+f	−4.7368+15.57(a)+16.88(c)−9.22(d)−22.10(f)	2.925	0.0216
c+d+e+b	−3.9607−100.49(b)+46.40(c)−27.43(d)−5.54(e)	2.954	0.0213
c+d+e+f	−3.8347+12.37(c)+0.49(d)−40.69(e)+39.28(f)	3.280	0.0181
c+g+e+f	−3.8534+12.93(c)−40.45(e)+38.73(f)−0.18(g)	3.294	0.0180
c+j+e+f	−3.9360+12.94(c)−40.28(e)+39.36(f)−0.31(j)	3.326	0.0177
c+g+a+f	−4.6143+16.25(a)+5.79(c)−13.40(f)+4.06(g)	3.378	0.0172
c+d+i	−1.1996+64.26(c)−55.97(d)−24.83(i)	3.423	0.0168
h+i+b	9.3911−153.97(b)−17.49(h)+15.89(i)	3.858	0.0136
h+e+f	2.2747−27.99(e)+47.38(f)−7.31(h)	3.931	0.0131
h+a	1.2512+8.63(a)−6.13(h)	4.028	0.0124
c+j+a+b	−4.5887+16.71(a)+34.25(b)+2.72(c)−0.75(j)	4.299	0.0109
h+k+b	5.8364−27.35(b)−11.39(h)−5.97(k)	4.837	0.0083
c+j+e	−4.4356+18.70(c)−50.31(e)+1.33(j)	4.915	0.0080
c+j+k+b	−2.4511−52.30(b)+20.45(c)−13.34(j)−10.60(k)	4.937	0.0079
c+d+e	−4.7362+20.37(c)−0.45(d)−53.43(e)	5.141	0.0071
c+e+b	−4.4680−1.36(b)+19.52(c)−52.48(e)	5.158	0.0071
c+g+e	−4.5797+19.68(c)−53.23(e)−0.02(g)	5.188	0.0070
h+e+b	8.1285−20.52(b)−45.07(e)−14.67(h)	5.509	0.0059
c+k	−4.3426+13.30(c)−5.31(k)	5.649	0.0055
c+i+b	−5.6775−141.73(b)+22.77(c)+17.24(i)	5.821	0.0051
c+k+b	−3.9708−12.84(b)+14.63(c)−6.46(k)	5.896	0.0049
h+a+f	0.4930+6.87(a)+19.67(f)−5.22(h)	6.083	0.0045
c+d+i+f	−1.0499+68.65(c)−59.91(d)−6.04(f)−26.58(i)	6.343	0.0039
Intercept only	N/A	20.428	0

Model weights shown here are re-normalized for the set of 37 top-ranked models shown. a = commercial; b = local roads; c = impervious; d = dense urban; e = apartments and condominiums; f = heavily used roads; g = light to medium urban; h = forest; i = residential; j = grass, crops and/or shrubs; and, k = industrial.
doi:10.1371/journal.pone.0023424.t003

for the syndrome's surprising uniqueness to adult coho are not yet known.

Daily or weekly stream surveys are labor intensive, and for this reason only a subset of urban drainages in Puget Sound have been monitored to date. The GIS-based mapping tool developed for this study can be used to focus future monitoring efforts on basins with a higher likelihood of coho die-offs based on land cover attributes. In addition to the basins we have identified within the range of the Puget Sound/Georgia Basin ESU, this approach could be extrapolated to other geographic areas where coho return to spawn along a gradient of urban growth and development. This includes, for example, coho from the Lower Columbia River ESU, a threatened population segment with a spawner range encompassing the greater metropolitan area of Portland, Oregon. Overall, future surveys will ground-truth initial model outputs and provide additional data that can be used to improve the predictive accuracy of the mapping tool.

Our findings have two near-term applications. First, they identify likely "hotspots" for coho spawner mortality throughout central Puget Sound. Given that recurring adult losses at a rate greater than approximately 10% are likely to substantially reduce local population abundances, the high mortality basins in Figure 3 (10–50% and >50% predicted mortality categories) may represent sink habitats for the Puget Sound/Georgia Basin ESU. This is an important consideration for coho recovery planning at the local, county, and regional scales. Second, our results indicate areas where toxic runoff could potentially undermine stream restoration efforts - specifically, strategies that improve physical and biological habitat conditions (flow, connectivity, channel complexity, riparian function, etc.) as a means to boost coho population productivity.

The potential influence of rainfall, including timing, frequency, and individual storm intensity, remains an area of active investigation. Throughout the years of stream surveys, it has been qualitatively evident that rainfall influences the mortality syndrome. For example, salmon that arrive and enter a stream during an extended dry interval (a week or more) often survive and then become symptomatic and die when it next rains (Scholz et al., unpublished data). One of our aims in surveying Longfellow Creek (the stream with the most abundant overall returns) for more than a decade was to evaluate inter-annual variation in coho spawner mortality in relation to rainfall. However, a quantitative analysis has proven problematic due to highly variable rainfall patterns in combination with low adult returns in some years. It is clear, however, that the syndrome is not a simple first-flush phenomenon. In most years, both egg retaining and spawned out carcasses were observed across the 8–10 week fall run, irrespective of the number and size of rain events over that interval.

Over the longer term, an approach similar to the one developed here could be used to forecast the likely impacts of future human population growth and development on Puget Sound coho populations that are currently healthy. For example, the expansion of local road networks is a core focus for urban growth planning, and these projections could serve as a basis for evaluating how and where coho spawner mortality will increase under different growth management scenarios. This, in turn, would inform strategies to reduce or mitigate toxic runoff in highly productive basins, in advance of expanding transportation infrastructure – i.e., prevention vs. costly retrofits to the built environment. Also, our modeling approach could be expanded to include the timing and intensity of rainfall as potential drivers for coho spawner mortality. Rainfall patterns may be a key determinant of stormwater quality, although more work in this area is needed. Climate change is expected to shift regional rainfall patterns, and it should be possible to explore how this will interact with changing land cover (urbanization) to influence stormwater quality and toxic runoff to coho spawning habitats.

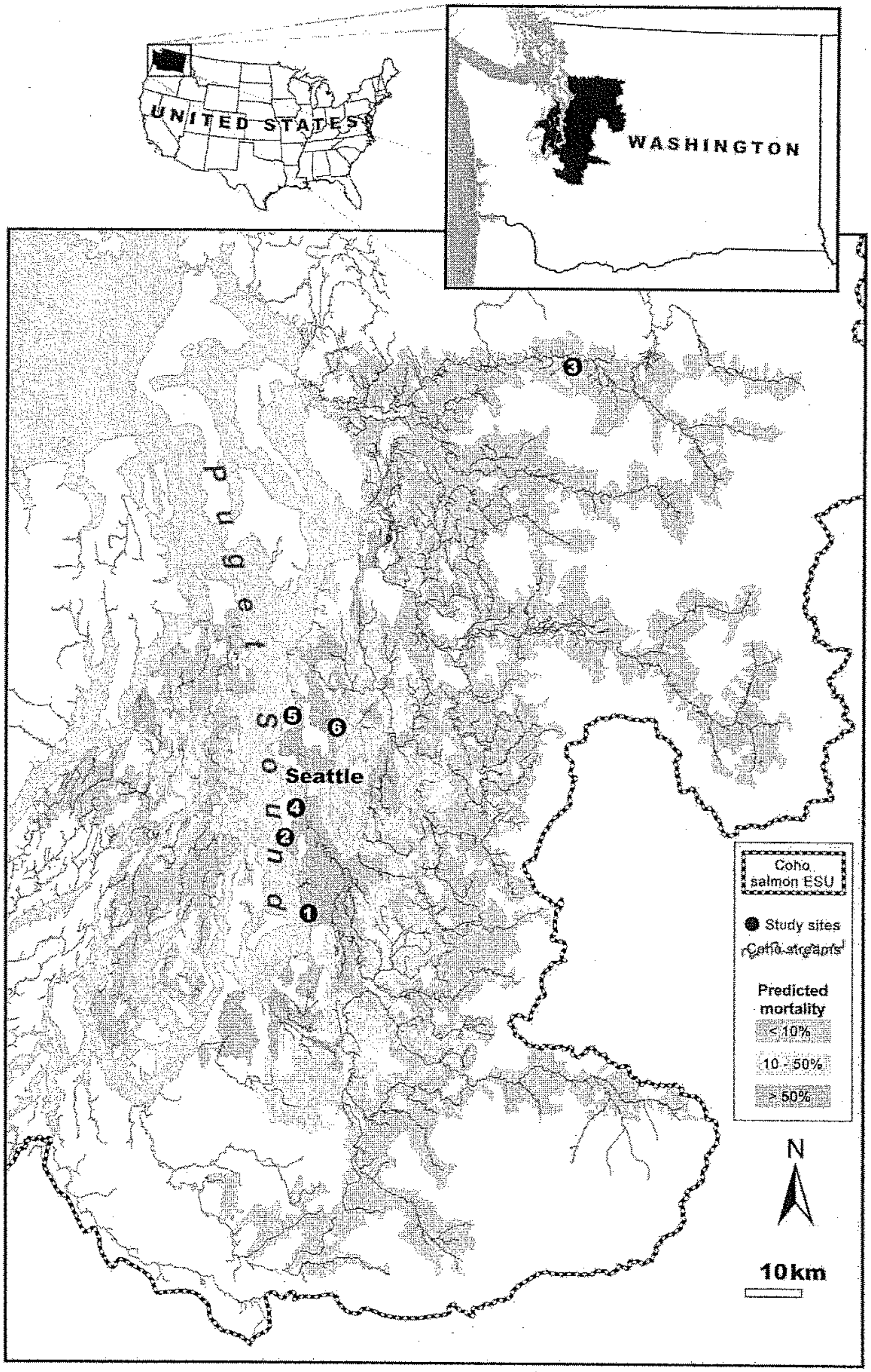
UNITED STATES
WASHINGTON
Puget Sound
Seattle
1
2
3
4
5
6
Coho salmon ESU
Study sites
Coho streams
Predicted mortality
< 10%
10 - 50%
> 50%
N
10km

Figure 3. Predictive map of modeled coho spawner mortality rates within the Puget Sound lowlands. Mortality rates are a function of the proportion of key landscape variables within a given basin. Green, yellow and red areas indicate basins with predicted rates of spawner mortality (as a percentage of total fall runs) of <10%, 10–50%, and >50%, respectively. Black dots denote locations of the six study sites that were the basis for this analysis. Thick dashed black line depicts the southern boundary of the coho salmon Puget Sound/Georgia Basin Evolutionarily Significant Unit (ESU). Basins that do not have documented presence of coho salmon [38] are not represented on the map, even if they have landscape conditions associated with coho spawner mortality. Key for site numbers: 1 = Des Moines; 2 = Fauntleroy; 3 = Fortson; 4 = Longfellow; 5 = Piper's; and, 6 = Thornton Creek.
doi:10.1371/journal.pone.0023424.g003

While not definitive, our results reinforce the parsimonious explanation that coho deaths are caused by one or more contaminants originating from motor vehicles. As noted earlier, this is important because it narrows the list of candidate toxics in complex urban landscapes. Future toxicological studies should focus on two ubiquitous urban runoff contaminant classes in particular. The first are metals in brake pads and other vehicle friction materials. Copper, zinc, and other metals are known to specifically target the fish gill, thereby disrupting respiration and osmoregulation [47]. The second, PAHs, [14,48,49] are taken up across the fish gill, and can impair cardiac function and respiration [50]. The symptoms displayed by affected coho (surface swimming, gaping, loss of equilibrium, etc.) are consistent with a disruption of respiration, osmoregulation, or circulation, or some combination of these.

Notably, PAHs and metals usually cause the above toxicological effects at concentrations well above those typically detected in urban streams. However, the majority of conventional toxicology studies using salmonids focus on freshwater species (e.g., rainbow trout) or the freshwater life stages of juvenile anadromous species. There are practically no toxicity data for coho salmon at the adult spawner stage. Many important osmoregulatory changes take place during the transition from seawater prior to spawning, and these may render adult coho more vulnerable to metals and PAHs than freshwater-resident salmonids. Adding to this complexity is the possibility of interactive toxicity (e.g., synergism) among contaminant mixtures. Studies that experimentally reproduce the familiar symptomology and mortality in adult coho, under controlled exposure conditions with environmentally realistic mixtures of metals and PAHs, will likely be necessary to definitively implicate motor vehicles.

Acknowledgments

We thank John Williams and an anonymous reviewer for significantly improving previous drafts of this manuscript. Disclaimer: the findings, conclusions and views expressed herein are those of the authors and do not necessarily represent those of the National Oceanic and Atmospheric Administration or the U.S. Fish and Wildlife Service.

Author Contributions

Conceived and designed the experiments: BEF JWD NLS. Performed the experiments: BEF ERB PA. Analyzed the data: BEF ERB PA. Wrote the paper: BEF ERB NLS.

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